IMPACTS OF EXTREME AND PERSISTENT TEMPERATURES — COLD WAVES AND HEAT WAVES

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1.
INTRODUCTION

The most extensive source of data on natural disasters is held by the insurance industry where the most important occurrences around the world are registered according to the number of deaths and the economic and insured damages incurred. Munich Reinsurance (or "Munich Re"), the world's biggest reinsurance company, has documented the 163 largest natural disasters that have occurred since 1960 in their "MRNatCatSERVICE" (1999a). Natural disasters are considered "large" when they considerably exceed self-help capabilities in the region concerned, making supra-regional or international help necessary. This is usually the case when the number of deaths are in the thousands and the number of homeless are counted in the hundreds of thousands, or when substantial economic damage is caused.

Vulcanoes	5
Earthquakes	45
Tropical cyclones	49
Tornados	7
Hail storms	7
Floods	27
Winter storms	11
Ice storm/blizzards	6
Fires	4
Droughts/heat	2

Figure 1. The biggest natural disasters 1960 – 1998. (MRNatCatSERVICE, Munich Re, 1999a).

Forty-five of these disasters were associated with earthquakes and 5 with volcanic eruptions i.e. about a third were not weather-related (see Figure 1). Only 1.2 per cent of the 163 disasters were caused by extreme heat and 10.4 per cent by extreme cold, making them very rare occurrences among the great catastrophes (For the 113 disasters caused by meteorological conditions, the corresponding percentages are 1.8 per cent and 15.0 per cent). Winter damage is not caused by low temperatures, but rather by freezing rain, heavy snowfall and high wind speeds that occur in such climatic conditions.

The insurance industry classifies disasters caused by atmospheric conditions as the result of "storm", "flooding" and "others", a classification system that is, at times, ambiguous. It is unclear, for example, whether flooding in Bangladesh, is caused by a typhoon, counts as a "storm" or "flooding". Equally, the data rarely indicate "cold" or "storm" as the cause of damage where ice storms or blizzards are concerned. Similar ambiguity also arises with drought and heat. According to insurance industry definitions, the issues addressed in this paper fall into the category classified as "others" (see Figure 2).

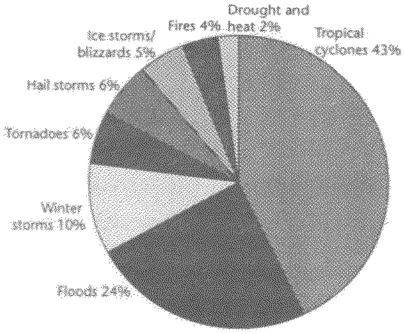


Figure 2. The biggest meteorologically induced natural disasters 1960 – 1998. (MRNatCatSERVICE, Munich Re, 1999a).

The occurrences identified in this paper are based on reviews of various information sources such as Climatic Perspectives, Transactions of the American Geophysical Union, Frankfurter Allgemeine Zeitung, Lloyd's List, Neue Züricher Zeitung, Monthly Weather Report, Property Claim Services, Online-Reuters, dpa, Süddeutsche Zeitung, Weekly Climate Bulletin, World Insurance Report, and others, supplied by the MRNatCatSERVICE of Munich Reinsurance (1999a-d). Only confirmed, cross-checked (usually) reports on the extent of damage, obtained from a reliable source, are accepted. For example, the plausibility of damage estimate is checked by the projection of total damage from the insured losses and the insurance density.

Sporadic worldwide information on drought/heat is available from 1910 onwards and more or less regularly since 1979. Reports on damage due to winter conditions begin in 1958, and have been available on a regular basis since 1971. Complete information is available since 1986.

2.
EXTREME TEMPERATURE EVENTS

2.1
COLD WAVES

2.1.1
Overview

The MRNatCatSERVICE lists 294 cases of winter damage (Munich Re 1999b). The description of associated meteorological conditions is not restricted to information on temperature, but also covers cold waves, unusually low temperatures, heavy snow falls, icing, dense fog, snow drifts, high wind speeds, severe precipitations, blizzards, frosts, freak snowstorms with typhoon force winds, snow pressure, freezing rains, ice rains, snowdrifts, snow depth, avalanches, torrential rain, persistent snow storms and floodings. Expressions such as heaviest or worst snowstorm, coldest winter or month, greatest depth of snow, longest duration for over a period of years, are also often used.

The following countries were affected by these conditions (frequency in brackets): Afghanistan (1), Albania (1), Algeria (1), Argentina (2), Australia (1), Austria (8), Bangladesh (11), Belgium (1), Belize (1), Brazil (4), Bulgaria (5), Byelorussia (1), Canada (25), Chile (1), China (3), Croatia (2), Czech Republic (1), Denmark (1), Estonia (1), European Region (5), Finland (3), France (11), Georgia (1), Germany (25), Greece (2) Guatemala (1), Hungary (3), India (13), Iran (2), Israel (2), Italy (11), Japan (5), Jordan (5), Kazakhstan (1), Korea, Republic of (1), Latvia (1), Lebanon (3), Malawi (1), Mexico (8), Moldavia (2), Mongolia (1), Namibia (1), Netherlands (2), New Zealand (4), Nigeria (1), Pakistan (2), Peru (2), Philippines (1), Poland (10), Portugal (4), Romania (9), Russia (12), Slovenia (2), South Africa (11), Spain (9), Sweden (6), Switzerland (8), Syria (2), Turkey (10), Ukraine (8), United Kingdom (5), United States of America (48), Yugoslavia (1). Of these 62 countries, about a third (21) experienced only a single extreme event while the statistics indicate that ten countries experienced 10 or more extreme occurrences. The US experienced 48, followed by Canada and Germany with 25 each, India with 13, Bangladesh, France, Italy and South Africa with 11 and Poland and Turkey with 10 cases. Countries also frequently experienced a series of disastrous events in the course of a single winter season.

Statistics display a wide range of damage types. There are various causes of death (e.g. 298 deaths in central and eastern Europe between 16 November – 18 December 1998 or 275 deaths in India between January/February 1992) and injuries from direct exposure to cold (e.g. as a result of an interruption of energy supplies), as a result of traffic accidents or avalanches and from being cut off from medical care.

Although there is generally a higher human mortality rate in the cold season in all climates, excess mortality can also be associated with cold spells in moderate climates (Jendritzky *et al.*, 1998) (Figure 3). Mortality increases within 2–3 days of the onset of a cold spell. This higher mortality rate lasts for some time and it is not completely compensated by subsequent reduced mortality. The medical causes of death are many. Direct influence of cold on the coronary circulation system and via the respiratory system is only one factor. Influenza and other infectious diseases, especially diseases of the respiratory system, are frequent causes of high winter mortality.

Damage to infrastructure ranges from the breakdown of power plants, power-supply and telecommunication systems and drinking water supplies (due to frozen pipelines), reduced oil and gas production and, in some areas, the isolation of human settlements from the outside world for weeks on end. Transportation on road, rail, water and air transport systems are hampered, with consequent reductions in economic activity and in the delivery of supplies to the population. Road traffic accidents increase. Agriculture and forestry are

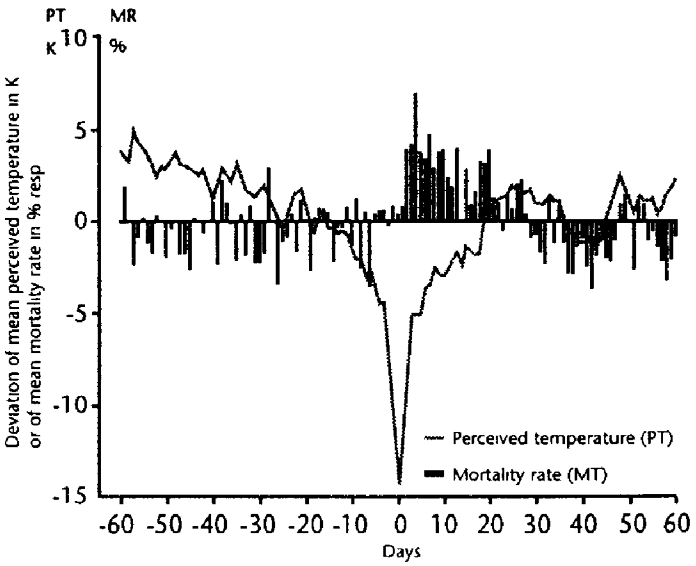


Figure 3. Extreme cold stress events. Averaged time series of mortality rate (MR), in per cent and perceived temperature (PT) (based on a complete thermophysiologically significant heat budget model of a human being) centred 60 days around the lowest PT value of each year related to their respective 30-day mean before the PT peak. Data 1968 – 1993 south-west Germany (Jendritzky *et al.*, 1998).

confronted with a loss of profits, even extending to total losses of field crops, fruit and vegetables. Examples include the loss of the grape harvest in large parts of France on 20 – 21 April 1991, 40 per cent of the Brazilian coffee harvest destroyed between 25 June – 25 July 1994, and huge losses of livestock in China with 1 million animals dying in 1986. Ice and snow also cause forest damage and the collapse of roofs.

Economic damage is enormous but is often difficult to estimate. Fairly reliable figures can, however, be derived for areas with high insurance density (Munich Re, 1999b). 14 countries or regions show economic losses greater than US $100 000 million, of which 6 have losses of more than US $1 million. Of the latter, 4 occurrences relate to the US (1977, 1994, 1996, 1998) and 2 to Canada (1992/93, 1998). The highest liquidated damages (US $4 million) resulted from extreme winter conditions in the northeastern USA, during January – March 1994, which experienced heavy snow, and rain and temperatures down to –40°C, resulting in the loss of 190 lives.

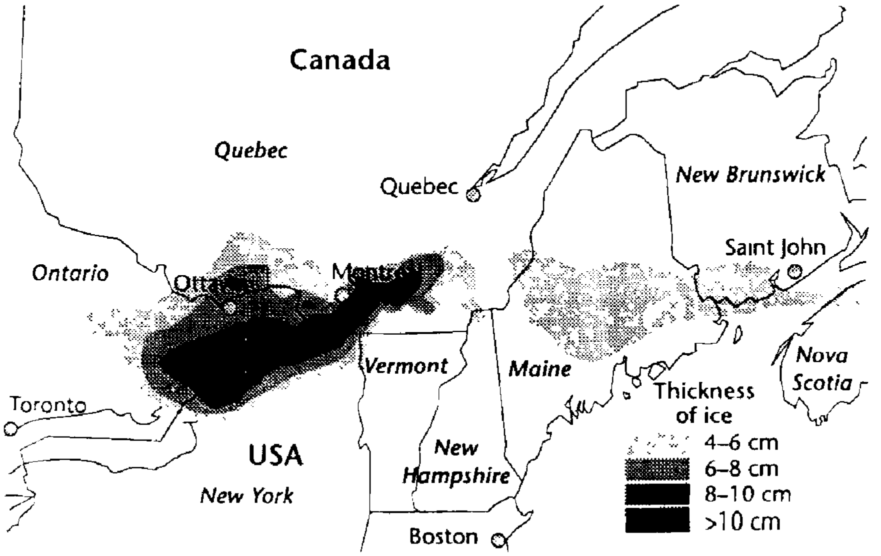
2.1.2
The 1998 Ice Storm in Canada and the US

The high damage potential of storms, ice and snow, even in moderate latitudes, is illustrated by the worst ice storm catastrophe in Canada's history, which occurred on 5–10 January 1998 (Savage 1998). Ice and snow storms (blizzards) belong meteorologically to the extratropical storms that originate in the transitional area between the subtropical and polar climatic zones, i.e. around 35–70° latitude. In this region, polar outbreaks of cold air encounter warm subtropical air and heavy precipitation often occurs along the boundary between these two air masses.

In January 1998, this situation prevailed in eastern Canada and in northeastern US. Very mild and moist air had advanced as far as the southern New England states, in advance of a cyclone moving up from the southwest. Cold arctic air was pushed south against this warm air by a powerful high pressure area over the Hudson Bay. Snow (mainly) fell to the north of the resulting sharp temperature gradient while to the south rain or sleet occurred which, with temperatures around freezing point, was transformed instantaneously to sheer ice on the deep-frozen ground and other surfaces. The landscape was slowly paralyzed under a continuously growing armour of ice that reached a thickness of up to 10 cm after six days, weighing up to approximately 100 kg/m^2 in some regions (Figure 4).

Between January 5–10, 1998, the total water equivalent of precipitation exceeded 85 mm in Ottawa, 73 mm in Kingston, 108 mm in Cornwall and 100 mm in Montreal (Savage 1998). Most of the precipitation fell as freezing rain and ice pellets with some snow. A representative temperature during the period was -10°C.

Figure 4. The January 1998 ice storm in eastern North America



Ice storms are not an infrequent occurrence in North America. In November 1921, for example, a similar severe storm produced 8 cm of ice while in January – February 1951, 10 cm of ice covered a record geographical expanse extending from New England to Texas. The severity of ice storms depends largely on the rate of accumulation of ice, the duration of the event and the location and extent of the area affected.

The extent of the area affected by this ice storm was enormous. At the peak of the storm, however, the area of freezing precipitation extended from Muskoka and Kitchener in Ontario through eastern Ontario, western Quebec and the Eastern Townships to the Fundy coasts of New Brunswick and Nova Scotia. In the US, icing coated northern New York and parts of New England. The area affected by freezing rain, therefore, extended for about 2 000 km in an east-west direction and 400 km in a north-south direction, a total area of approximately 800 000 km^2, while an armour of ice more than 4 cm thick covered a region of almost 100 000 km^2.

The reason that this occurrence turned into a catastrophe was, firstly, its unusually long duration of around a week*. The number of hours of freezing rain and drizzle was in excess of 80, nearly double the normal annual total. Secondly, the thickness of the ice layer and its enormous expanse, covering one of the largest populated and urbanized areas of North America, left more than four million people freezing in the dark for hours or days.

The following statistics provide an insight into the impact of the storm (Munich Re, 1999c, Savage 1998):

Deaths: 23 (Canada: 16, USA: 7);

Injured: several (!!);

Evacuated: 100 000.

Power breakdowns: More than 4 million people without electricity and heating (On 22 January 1998, 800 000 people were still without electricity in Canada).

120 000 km of power and communication lines destroyed (including 130 major transmission towers each worth US $100 000, and about 30 000 wooden utility poles costing US $3 000 each). The damage was so severe in eastern Ontario and southern Quebec that major rebuilding of the electrical grid had to be undertaken.

Damage: Houses damaged by fire, broken pipes, destroyed roofs; many cars damaged; 2 oil refineries, copper and aluminium plants, factories, businesses and shops affected (business interruptions, loss of income).

Infrastructure: Highways, roads, bridges closed; roads and bridges damaged; railroads blocked, signalling systems frozen, train services suspended; air traffic affected; subway systems disrupted; airlines and railways discouraged travel into the area.

Miscellaneous. Water treatment plants affected; drinking water supply failure. Residents were urged to boil water for 24 to 48 hours.

Forestry and Agricultural losses. Major losses to forests, hundreds of thousands or even millions of trees downed or severely damaged; losses to livestock and dairy farms, milk processing plants closed. Many Quebec maple syrup producers (who account for 70 per cent of the world supply) were ruined with much of their sugar bush permanently destroyed.

Resources mobility: 14 000 troops, including 2 300 reservists, deployed to help with clean up, evacuation and security.

Insurance claims lodged 612 000 single damage claims were filed with insurance companies. The most frequent claims were for:

Food which had gone bad, in refrigerators without electricity supply (Insured up to US $1000 in many household policies);
Burst water pipes caused by freezing due to the failure of heating systems;
Roof damage due to ice pressure and fallen trees;
Procurement of electric generators to prevent potential damage;
Additional living costs such as for hotel accommodation;

Total economic damage: Canada: US $1 500 million
USA: US $1 000 million

Insured goods: Canada: US $950 million
USA: US $200 million

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* Though it did not rain continuously throughout this period

Had this storm tracked 100 km farther east or west of its actual path, the disruptive effect would have been far less crippling.

2.2 HEAT WAVES

2.2.1 Overview

A distinction is not usually made between droughts and heat waves in the data tabulated by the MRNatCatSERVICE, (Munich Re. 1999d). In total, 347 such cases are listed and most of them are categorized under the drought heading, starting with a reference to the 1910-1914 drought in the Sahel region. However, 46 of these cases are clearly identified as "heat waves", 12 as "drought/heat waves" and in 17 droughts there is explicit mention of high temperatures, often in relation to their unusual duration.

According to the above listing, the following countries were affected by heat waves, drought/heat waves or high temperatures (frequency in brackets): Australia (5), Bangladesh (1), Canada (1), China (4), Croatia (1), Cyprus (1), Denmark (1), Egypt (1), Germany (3), Greece (2), Hungary (1), India (8), Japan (2), Kazakhstan (1), Korea, Republic of (3), Morocco (2), Mexico (5), Moldavia (1), Mozambique (1), Namibia (1), Pakistan (6), Peru (1), Romania (3), South Africa (2), Spain (1), Swaziland (1), Turkey (1), Ukraine (1), Uruguay (1), United States of America (8), Venezuela (1), Vietnam (2), Zambia (1), Zimbabwe (1). Thirty-four of these countries appear in the statistics several times. In particular, India and the USA have each experienced 8 occurrences, Pakistan 6, Australia and Mexico 5, China 4 and Germany, the Republic of Korea, and Romania each had 3 heat waves.

The damage resulting from heat waves ranges from losses of agricultural products and livestock (causing food shortage, hunger and bankruptcy of farmers) to forest and bush fires, power failures and power cuts due to water shortage and inadequate supplies of fresh drinking water. At times, droughts associated with heat waves can cause immense damage to the economy. In 1988 in the USA, for example, economic damage amounted to US $13 000 million during a drought extending from Ohio to California. Temperatures were around 40°C, 30 states were affected and a state of emergency was declared in 12 states. Temperatures in Texas reached 38°C on 29 consecutive days during 1988, 130 people died and US $4 275 million in damages resulted. Similarly, in 1996, US $1 200 million in losses occurred in Mexico and US $2 400 million in the USA, while in 1992, losses estimated at US $1 000 million were experienced in the states of southern Africa.

Exactly half of the 76 reports on heat waves identified earlier contain reports of deaths and a lesser number refer to injured persons During 13 of these occurrences more than 100 persons died. The highest single number of deaths, 3 028, was reported from India in 1998, followed by approximately 2 000 in Greece in 1987 (Katsouyanni *et al.*, 1988) and 1 444 in China in 1988. In China, many people were, apparently, killed by a sudden rise in water level in dried-out river beds. India, Pakistan and Bangladesh are particularly susceptible to heat waves and several hundred people died in the droughts that occurred in 1988, 1991, 1992 and 1994. The July 1995 heat wave in the Midwest of the USA had the gravest consequences with 670 deaths (up to 830 according to other sources!), of which 375 (some sources say 525) occurred in Chicago (CDC 1995, Kunkel *et al.*, 1996, Changnon *et al.*, 1996) (see 2.2.2).

Available insurance data do not permit clear identification of the exact cause of death (heat, hunger, other causes) because of the ambiguity between drought and heat wave. This presents a fundamental difficulty in the case of pure heat waves where the deviation of daily mortality from the expected value in the period under consideration can be calculated (excess mortality) All countries with adequate hygiene and an efficient health system show minimum mortality in the summer months as previously feared summer infections are now under control. Heat waves, however, occur during this period and anyone without air-conditioning buildings heat up (the urban heat island). The people who die in such conditions are mainly elderly people with limited adaptability (U.S. Senate Special Committee on Aging 1983). The reference to the thermal properties of buildings and air-conditioning also illustrates the socio-economic dimension of the problem.

As a general rule, excess mortality represents a displacement of the death date of susceptible persons by a few days or weeks ("harvesting") (Figure 5). This is subsequently compensated for in the mortality time series by reduced mortality There are studies, however, which show that this compensation is incomplete i.e. people die who would have lived longer without the additional stress of the heat wave (Kalkstein 1993, 1995). It has not been clarified whether a threshold has to be crossed to cause this biological stress (Figure 6). In essence, the term heat wave has not yet been quantitatively defined. A generally applicable definition cannot be found since, with the exception of intensity and duration, the regional climate and frequency of occurrence within the summer season will certainly play a role.

A US survey by Changnon et al. (1996) on the relationship between deaths and weather since the beginning of this century is of interest in the present context. This study shows that the number of deaths during heat waves (annual mean 1 000; extreme values from 9500 to 10 000) exceeds the number during all other extreme weather conditions such as hurricanes (annual average 38-63; extreme values 1 836-6 000), heavy rains/floods (100-160; 732-2 200), tornadoes (82-130; 322-739), winter storms (130-200; 270-500), lightning (100-154; unknown), winter storms (60-115; 105), and hail (1; 22)*.

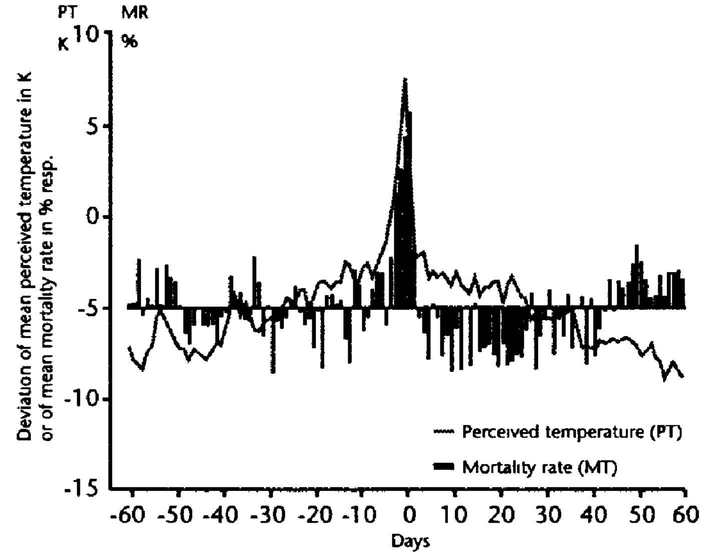

Figure 5. Extreme heat load events. Averaged time series of mortality rate (MR) in per cent and perceived temperature (PT) (based on a complete thermo-physiologically significant heat budget model of a human being) centred 60 days around the highest PT value of each year related to their respective 30 day mean before the PT peak. Data 1968 – 1993 southwest Germany (Jendritzky *et al.*, 1998).

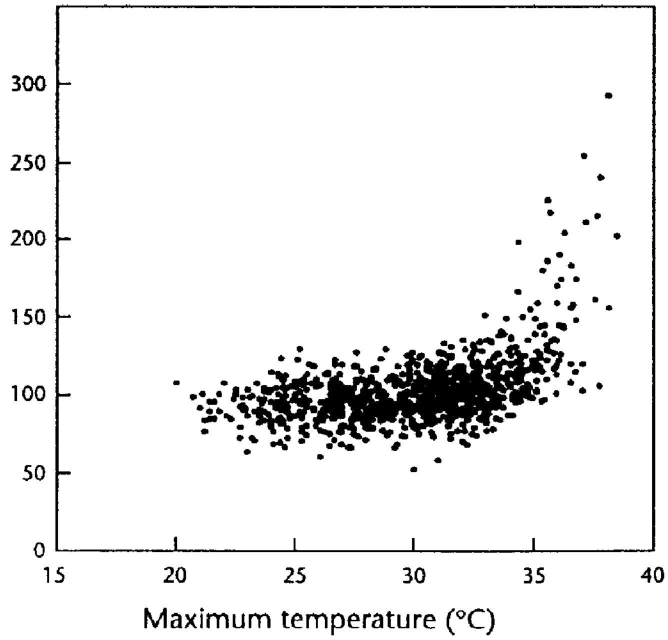

Figure 6). Relationship between maximum temperature and mortality in Shanghai, China, showing a threshold (Kalkstein 1993).

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* The values quoted are based on data for different base periods and from different sources and should only be considered as relative measures

2.2.2 The 1995 Heat Wave in Chicago

A severe 5-day heat wave hit the central United States in July 1995, extending from 11–17 July (for details see Changnon et al. 1996 and Livezey and Tinker 1996). Apparent temperatures* exceeded 40°C during daytime and, probably even more serious, nocturnal temperatures in urban areas remained above 30°C. The urban heat island was insignificant during the daytime but substantial at night (Figure 7). This severe heat wave caused 830 deaths, with 87 per cent occurring in the Midwest including 525 in Chicago alone. Deaths commenced one or two days after the heat wave, with most occurring in the 4-day period between 13–16 July. Seventy three per cent of those who died from heat-related causes were persons aged 65 or older (Whitman 1995). Most deaths occurred in homes without air conditioning or where the residents did not operate air conditioning or fans because they were unable to afford them.

Some confusion exists regarding the precise number of deaths. Firstly, there is no general definition of a death due to heat. Heat stroke is clear as a cause of death, but affected individuals also often suffer from other health problems. Thus, questions arise as to whether heat is the primary cause of death or only a contributing factor? An additional problem is caused by the 1 to 2 day delay in reporting deaths, due to overloaded medical examiners. A study of excess deaths during heat waves, probably the best measure of heat-related deaths, suggests that actual heat-related deaths are generally underestimated by a factor of ten (Avery 1988) !

The 1995 heat wave also caused many other types of impacts. Energy usage increased enormously, reaching an all-time record high. 40 000 people were affected by a massive power failure during periods of peak stress. Energy use led to an increase in electricity bills, a problem for low-income families. Hospitals in the Chicago area became overloaded and the number of ambulances was completely insufficient to handle the crisis as thousands were taken to local hospitals. Highways and railroads were damaged and companies reported that productivity was greatly reduced. About 850 dairy cows died, milk production declined and major flocks of poultry were killed.

An assessment of the reasons for the severity of the heat-wave (Changnon *et al.* 1996) revealed that many factors were to blame:

- An inadequate local heat wave warning system, though the National Weather Service issued accurate short- and medium-range forecasts;
- The urban heat island;
- The inability of many people to properly ventilate their residences, due to fear of crime or a lack or resources for fans or air conditioning;
- Power failures; and
- Inadequate ambulance service and hospital facilities.

These contributing factors indicate a lack of preparedness at various levels. The social and demographic factors (i.e. increased population in urban areas, a generally older population, reduced home/apartment ventilation for fear of crime, ignorance, high electricity bills, changing ethnicity) would indicate increased likelihood of heat deaths in large urban areas (Changnon *et al.*, 1996).

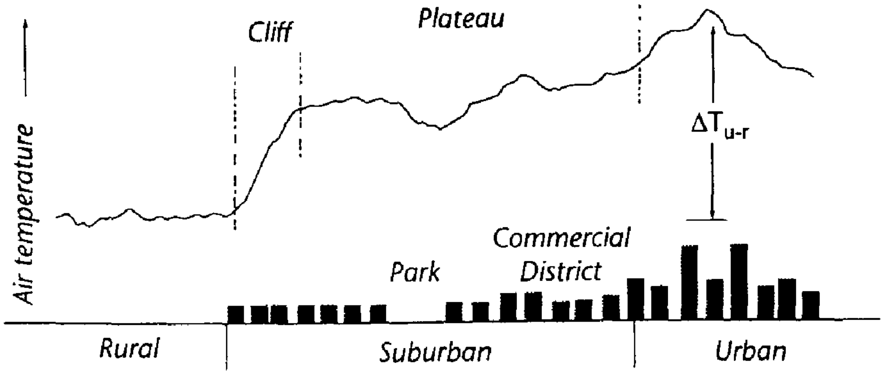

Figure 7. The urban heat island effect on night-time minimum temperatures.

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* An index based on air temperature and relative humidity, which reflects the heat dissipation of a human body (Steadman, 1979)

3. THE METEOROLOGICAL AND CLIMATOLOGICAL CONTEXT

Weather-related disasters are concentrated in a few extreme events. The examples in Chapter 2 indicate that the worst disasters in winter are rarely related to extremely low temperatures but to particular meteorological conditions. In the 1998 winter storm in Canada, a jet stream brought an abundant amount of rain northward which, for five days, fell through a shallow layer of cold air at the surface, producing super-cooled water droplets which froze on impact on all surfaces.

Regional effects are significant for heat waves, such as the moisture uptake of the air-mass and cloud cover as it affects nocturnal cooling. In addition, the urban heat island effect contributes to the adverse affects of the high minimum temperatures. Thus with heat waves, various conditions must come together in order to produce extreme impacts.

There are meteorological teleconnections associated with ENSO events due to the response of the global atmospheric circulation and these alter weather patterns worldwide (Leathers 1994). The 1997-98 El Niño, the "climate event of the century", for example, caused sweltering summer heat in from the Indian subcontinent to China, including the most severe heat-wave this century (Shabbar 1998). Temperatures reached 49°C in India and 3 028 individuals died. On the other hand Livezey and Tinker (1996) found little support for ENSO as a contributing mechanism for the Chicago heat wave 1995. There is no evidence that ice storms in eastern Canada are more frequent during El Niño winters though the 1998 ice storm may have had an "El Niño signature" (Shabbar 1998). Whatever the case, Canada's worst ice storm occurred while the region was experiencing a warmer winter with less rain or snow than usual. While the effects of El Niño are more direct and dramatic in the tropics, La Niña effects seem to be more distinct in the northern hemisphere winter. This is evidenced by the extreme low winter temperatures associated with La Niña events.

Because natural climate variability is extremely high, it is impossible to tie individual events directly to a specific global force such as climate change. There is, furthermore, no consensus as yet concerning the suggested linkages between climate change and intense El Niños. It is expected that in a warmer world with intensification of the hydrological cycle, extreme events should become more frequent. It is not, however, clear what this means with respect to extreme temperatures. Temperatures close to freezing point and additional precipitation are likely to occur frequently during warmer winters. Consequently, the frequency of ice storms could increase. Simple displacement of the climatological temperature distribution of a given site or area to a higher mean as climate warms would suggest an increase in heat wave events and a decrease in cold spells. Equally, a change in the direction of increasing variability could result in more extremes of both types (Figure 8).

Every National Meteorological Service should be in a position to forecast threatening conditions in order to protect life and property. Using state-of-the-art NWP models, extreme temperature events cannot be forecast beyond the theoretical limit of dynamic predictability of 2 weeks and, in practical terms, beyond about 1 week (Livezey and Tinker 1996). Investigation of the adequacy of the

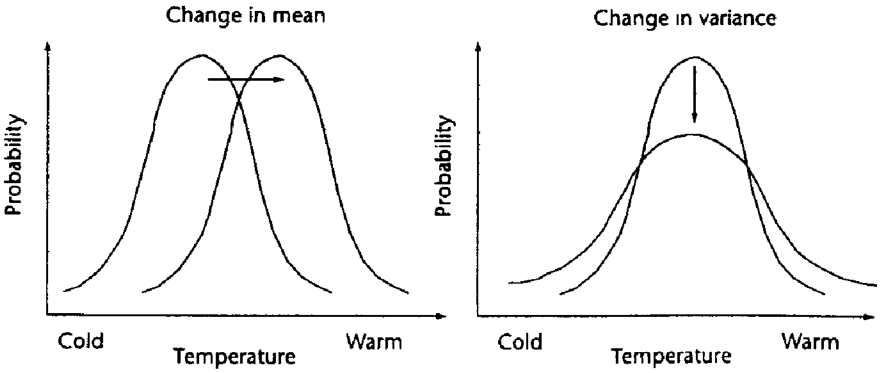

Figure 8. Possible changes in frequency distribution of temperature
(Maskell et al., 1993).

1995 Chicago heat wave forecast clearly showed that the forecasting was accurate and its onset was recognized several days in advance (Changnon *et al.*, 1996).

4. VULNERABILITY

The MRNatCatSERVICE statistics on extreme weather events, referenced in sections 2.1.1 and 2.2.1, certainly contain errors, particularly during the earlier years of record. This database, nevertheless, permits some general conclusions to be drawn. Countries at different stages of development are represented in the statistics. While developed, newly industrialized and developing countries are all affected by cold wave or heat wave events, some higher risk areas can be identified. These include the middle latitudes of North America, central and southern Europe, South-East Asia from Pakistan to India and Bangladesh to China, the southern region of Africa and, mainly in summer, Australia. For a variety of reasons, vulnerability differs from country to country.

Modern industrial societies usually show a high sensitivity to disasters because they depend strongly on undisturbed, ongoing access to a well-developed infrastructure, particularly transportation and electricity. More and more people live in expanding urban areas with high settlement density where values are often concentrated in high risk locations. Intensive forms of agriculture and livestock farming are carried out. Emergency preparedness is usually underdeveloped due to lack of awareness, particularly in moderate climates, and most people do not understand the danger presented by different weather conditions (Changnon *et al.*, 1996).

People in less developed countries are also increasingly concentrated in rapidly growing urban agglomerations or megacities. Their vulnerability is, to a greater extent, determined by the lack of financial resources, inadequate infrastructure, accelerating deterioration of natural resources and wars. While economic losses and insured losses are usually much higher in developed countries, data frequently indicate a greater number of deaths in the less developed regions.

Cooperative action involving all levels of government, private companies (e.g. insurance industry) and non-profit institutions, and associations and the natural and technological community is necessary in order to reduce loss of life and damage to property caused by the impact of natural disasters. As mitigation is understood as the cornerstone of emergency management, a good example has been set in North America by the US Federal Emergency Management Agency (FEMA) and Emergency Preparedness Canada (EPC). These agencies have developed mitigation strategies "to protect the nation's critical infrastructure from all types of hazards through a comprehensive, risk-based, emergency management program of mitigation, preparedness, response and recovery" (FEMA). The aim is to bring about a safer and more disaster-resistant country.

5. THE WATCH/WARNING CONCEPT

Although short- and medium-range weather forecasting has, in general, improved significantly in recent years, the results are better at the macro- and meso-scales than at the micro-scale. For heat waves, however, the superimposed micro-scale urban heat island effects are more significant than the regional pattern (Riebsame *et al.*, 1991), taking into account local socio-economic and demographic factors. This illustrates that meteorological assessments must be tailored to the specific problem being addressed (e.g. adequate criteria have to be established for warnings) Similar guidance applies to monitoring of the preceding weather situation in order to alert responsible agencies and the public, well in advance, that conditions are favourable for the development of an extreme event.

An accurate and adequate meteorological forecast by the National Meteorological Service (NMS) is a prerequisite for providing warnings. In addition, the interface between the NMS and the emergency response decision maker (e.g. in the health department) must be formally established, in advance. Clear definition of responsibilities is necessary to ensure criteria are met, to establish the progression from watch through warning to emergency, and to alert all affected agencies and the public on the basis of a prepared plan. The heat watch/warning system, first established in Philadelphia (Kalkstein 1995) and presently being implemented in some other large cities outside the USA, under the umbrella of WMO, WHO and UNEP, is an excellent example of such an integrated procedure (Figure 9).

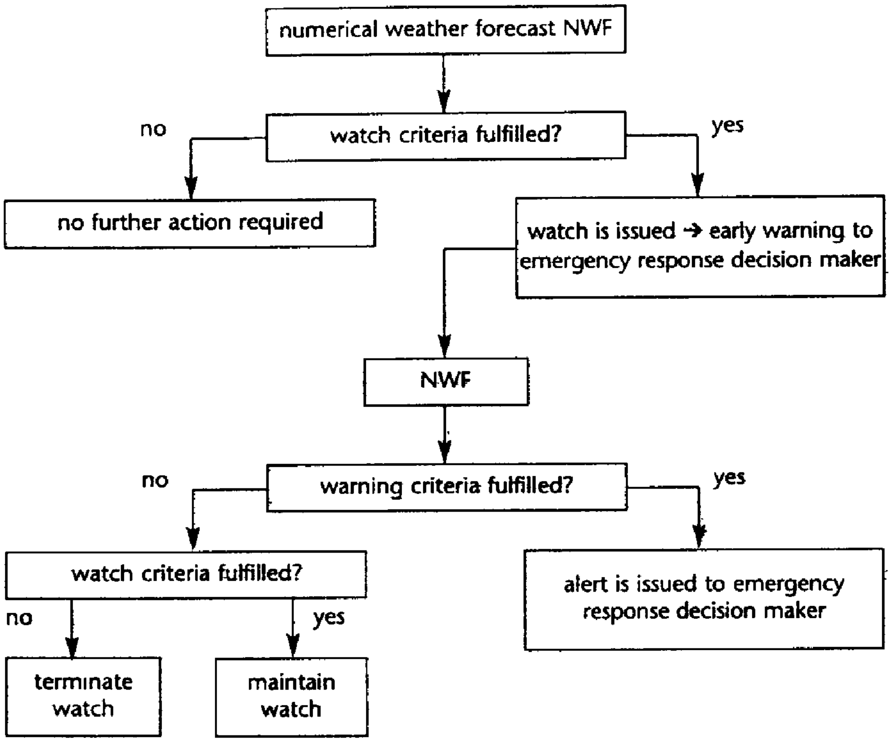

Figure 9. Flow diagram illustrating the heat watch/warning decision process.

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