STATEMENT FROM THE WMO/UNESCO SUB-FORUM ON SCIENCE AND TECHNOLOGY IN SUPPORT OF NATURAL DISASTER REDUCTION

(Geneva, 6-8 July 1999)

One of the outstanding achievements of the International Decade for Natural Disaster Reduction (IDNDR) has been its major contribution to increased interaction and cooperation between the natural and social science communities working in disaster reduction and thence to enhanced application of science and technology to reducing the large and growing social and economic cost of natural disasters around the world.

Though science and technology have already contributed much to saving human life and reducing property loss and environmental damage from most forms of natural hazard of meteorological, hydrological, oceanographic and geological origin, their potential contribution over the next decade is even greater. But only if they are systematically and wisely applied within the broader social context of an integrated approach to natural disaster reduction which is the principal legacy and proudest achievement of the IDNDR.

In order to assist the global community to build most effectively on the foundation provided by the IDNDR, the World Meteorological Organization (WMO) and the United Nations Educational, Scientific and Cultural Organization (UNESCO), as the two principal United Nations agencies concerned with the scientific and technological aspects of disaster reduction, convened a "Sub-Forum on Science and Technology in Support of Natural Disaster Reduction" as a special contribution to the 1999 IDNDR Programme Forum "Partnerships for a Safer World in the 21st Century".

The Sub-Forum reviewed the various ways in which science and technology contribute to the disaster reduction process through, the:

- Assessment of vulnerability and enhancement of community awareness of the nature of the risk;
- Operation of integrated warning systems; and
- Preparedness and education programs.

In its review, the Sub-Forum took stock of recent progress and future prospects in each of these three aspects of the application of science and technology to reduction of the impacts of tropical cyclones, extratropical storms, storm surges, severe local storms and tornadoes, sand and dust storms, drought, extreme and persistent temperatures, fire weather, floods, landslides, avalanches, volcanoes, earthquakes and tsunamis. A synopsis of this review is contained in the Annex to this statement.

The participants in the Sub-Forum, who came from both the natural and social sciences and with both research and operational backgrounds in developing and developed countries were concerned that more could have been achieved during the IDNDR decade if the channels of communication and mutual trust that have now been achieved could have been established earlier. They were also concerned at the substantial gap that still exists between the disaster reduction capabilities of the developed and developing countries. They believe, however, that the achievements of the past decade have provided a sound foundation on which to build an effective global strategy for natural disaster reduction in the 21st century.

MAJOR ACHIEVEMENTS

Many of the most significant achievements in natural disaster reduction during the 1990s were largely a result of science and technology. Accuracy and timeliness of early warnings for many natural hazards have been improved. The ability to provide forecast time and location of landfall of tropical cyclones has been improved by 24 hours so that the accuracy of the 24-hour forecast in 1990 has been increased in 1999 to 48 hours in advance. The warning time for tornadoes in 1990 was around 8 or 9 minutes and this has nearly doubled to over 17 minutes by the end of the decade. In the past decade, information and understanding on specific natural hazards such as earthquakes and cyclones has, along with increased confidence of design engineers and insurance companies, permitted improvements in building codes and standards in many parts of the world. A related achievement has been the significant increase of available maps of risk for many countries based on scientific studies and analyses of the climatology of natural hazards.

Perhaps the most visible achievement in the 1990s has been the creation of new disaster management bodies at all levels of government that now include scientists and engineers involved in the study and prediction of natural hazards. One of the major meteorological concerns of the 1990s had to do with the longer time scales associated with seasonal to interannual climate variability and human-induced change. While the capacity to forecast these changes is still limited, the implications for natural disaster reduction are extremely significant with just a very small improvement in forecast skills likely to lead to major benefits for communities and national economies.

Another notable achievement of the decade has been the ability, by means of satellites, to detect, track and assess the intensity of tropical cyclones and major storm systems. It is almost a certainty that all tropical cyclones can now be detected at or before their development as a natural hazard.

Significant improvements have been made during the decade in the global observation system of the World Weather Watch (WWW) and the Integrated Global Ocean Services System (IGOSS). For example, the polar and geostationary satellite systems have been enhanced and the experimental buoy network in the tropical Pacific Ocean has been made operational providing essential observations for early detection of intense El Niño and subsequent La Niña phenomena. This achievement permitted prediction of drought and above-normal precipitation several months in advance in Eastern Africa, and prediction of heavy rain in California in the United States. These predictions also led to special preparedness actions resulting in significant loss reduction in the ensuing flooding.

Overall, the achievements in scientific understanding and its application during the 1990s have provided significant increases in evacuation times, better building standards, and improved risk assessment.

VULNERABILITY AND AWARENESS

The Sub-Forum agreed that vulnerability assessment and reduction should form an integral part of the follow-up to the IDNDR. This should be achieved through use of advances in engineering, as well as in the natural, social and human sciences.

Awareness raising on all types of natural disasters forms an essential element in early warning systems, particularly where warning periods are short. It encompasses the affected population as well as the political authorities concerned. Therefore, education and training of communities at large, the involvement of media and continuous interaction between scientists, sociologists, technologists and decision makers and governmental authorities are indispensable vehicles for effective implementation. The partnership of scientific and technical practitioners with those working in social and humanitarian fields is essential notably in urban areas, involving the local population as well as tourists.

In developed countries, it has been clearly demonstrated in recent years that the vulnerability of communities to natural hazards can be greatly reduced by the use of modern building standards in conjunction with risk zoning based on scientific and technical knowledge of the various hazards and their impact on the built environment. Indeed it is through such standards and risk zoning that much of the scientific and technical knowledge of the various hazard mitigation is applied in the community. In the building and construction areas these standards are being developed by the International Standards Organization (ISO). These standards have the potential to greatly reduce community vulnerability to a number of major hazards in the long-term but this will require that the development of these new international standards be given higher priority than the revision and upgrading of their individual national standards.

A related, but separate need, is the development of cost-efficient means of reducing the vulnerability of existing buildings and infrastructure and the financing of activities. This is required to address the reduction of vulnerability in the short- to medium-term. A high level of technical skills will be required to determine economic means of reducing the vulnerability, as well as a high-level of scientific and engineering expertise for the innovative methods of risk financing needed to securitize the investment in reducing the vulnerability.

INTEGRATED WARNING SYSTEMS

Early warnings are an extremely important link in the series of steps that need to be followed to reduce the social and economic impact of natural hazards. Warnings of a natural hazard such as a flood delivered in a timely and clear manner to individuals or communities adequately prepared to take action reduces the impact of the hazard.

All sectors must be involved in the warning process and serve population needs, environment and other national resources. Effective early warnings require unrestricted access to data that is freely available for exchange and they must emanate from a single officially designated authority.

Advances in science and technology during the past decade have demonstrated the improved warning capability for many natural hazards in many parts of the world. For example, warnings of drought have been issued several months in advance which proved of great value for alleviating the impacts of the drought and the likely resulting decrease in food supplies. The forecast accuracy of tracks of tropical cyclones has shown significant improvement and average forecast lead times for tornadoes and flash floods have been substantially increased with the concomitant reduction in loss of life.

Provided adequate assistance is available, many opportunities now exist, in the coming decade, to transfer these warning capabilities to areas affected by natural hazards especially in developing countries.

The warning process is underpinned internationally by the World Weather Watch and IGOSS, the Tsunami Warning System and associated research particularly the World Weather Research Program. At the national level this process includes local and regional observational systems such as coordinated hydrological networks and radar, data processing capability and most importantly it depends on well-trained meteorologists to prepare forecasts and warnings and interact with media and emergency management officials.

PREPAREDNESS AND EDUCATION

A wide range of activities and bodies is encompassed in the terms "preparedness" and "education". They extend from the grass roots to the governmental level and involve individuals, families and communities at one end, and universities, ministries and government as a whole at the other. They take in classes, seminars, schools, links of various sorts such as between the forecasters and the audience for their forecasts; and they include research, not only into forecasting, but also into the delivery and dissemination of forecasts and warnings and the responses, perception and reactions to them.

Developed and some developing countries have extended their preparedness and the meteorological, hydrological and other geoscience products supporting it into new areas in the course of the IDNDR decade. A closer dialogue has been forged between the scientific community and stakeholders in various areas of endeavour, such as agriculture, health and transport, and good progress has been made in the dialogue with social scientists, but this area still needs more attention. Catering for preparedness of the disadvantaged and disabled has also not progressed to the desired extent and greater use of plain and meaningful language is seen as highly advantageous in the better communication of forecasts and warnings. Indeed the language of preparedness measures and forecasts determine the way these messages are accepted. In many cases the use of a dialect could improve effectiveness and credibility. Confirmation of such messages is also an important consideration. Using mobile phones and pagers to propagate these messages and means other than radio and television have distinct benefits. Education and training applied in the direction of those scientists building the preparedness measures as well as those they are designed for. Indian experience of workshops between forecasters and people using their forecasts pointed to the value of such exchanges. However, there are differences when carrying the message to adults as opposed to children.

There are advantages attached to the education of schoolchildren in disaster preparedness – their parents benefit as well and this has been made evident during the IDNDR. Developing countries trying to build their preparedness face enormous costs and also the much greater costs of reconstruction in the wake of a disaster.

FUTURE ACTIONS

The Sub-Forum recognized that, as a result of demographic pressures and concentration and other factors, our societies are becoming more and more vulnerable and that our protective systems are not necessarily adapted to cope. Furthermore, considering that a disaster strategy which puts emphasis solely on relief and response is short-sighted and not cost-effective, the participants agreed on the need for greater emphasis on prevention across the whole continium of hazards faced by humanity.

The Sub-Forum recalled that the 1994 Yokohoma World Conference on Natural Disaster Reduction called for a construction of a "Culture of Prevention" which should be based on improved short-term and long-term monitoring mechanisms. Mitigation, preparedness and prevention measures must be proactive rather than reactive; they must provide the correct treatment while there is still time. Prevention must be rooted ultimately in culture and education which finds its expression in our everyday social behaviour. Hence, the threat of potentially irreversible events includes an ethical dimension which should be reflected in training, organization and motivation of communities at risk.

Capacity building and education at all levels have an important role to play in the development of a culture of prevention by ensuring a two-way flow of information between decision makers and communities at risk.

The Sub-Forum emphasized the need for capacity-building in vulnerability and risk assessment, early warning of both short-lived natural disasters and long-term hazards associated with environmental change, improved preparedness, adaptation, mitigation of their adverse effects and the integration of disaster management into overall national socio-economic development planning.

The participants agreed that a focussed ongoing coordination structure is needed within the UN system in order to strengthen further the already close cooperation among intergovernmental and non-governmental scientific and technical bodies committed to natural disaster reduction. Such a mechanism is necessary to foster and sustain the vital international and national effort on the application of the natural and social sciences and technology in support of natural disaster reduction, particularly through the implementation of the relevant programmes of UNESCO and WMO.

EXTRATROPICAL STORMS OF THE DECADE - A BRIEF REVIEW

By William Appleby and Karen Sutherland
Environment Canada, Atmospheric Environment

ABSTRACT

Large-scale, mid-latitude storms are responsible for a variety of extreme weather. They are the main cause of blizzards, freezing rain and heavy snowfall in winter and can cause intense rainfall, hailstorms, or spawn tornado families in summer. The 1990s have seen an increase in the cost of natural disasters resulting from extratropical storm activity, both in terms of financial costs and human lives, despite improvements in risk forecasting. The following are examples of large-scale disasters caused by extratropical weather events. The 1998 flooding of the Yangtze River in China claimed 3 700 lives as excessive rainfall inundated the area for 60 days. The floods dislocated 223 million people and cost US $30 billion in damages, making it the most costly disaster of 1998. The Ice Storm that hit the Eastern provinces of Canada and Northern parts of the New England States of the United States of America in January 1998 coated every exposed surface with a layer of ice about 70 mm thick. This ice storm was the worst to hit Canada in recent history. Prolonged freezing rain brought down millions of trees, over a thousand hydro towers and more than 100 000 km of power lines. The storm claimed at least 25 lives and nearly 3 million people went without electricity or heat and about 100 000 people took refuge in shelters. The resulting damages cost close to US $2 billion. While El Niño and other phenomena may intensify weather conditions, the greater problem may be that more people are living in vulnerable areas and take insufficient precautions, despite great advancements in public safety warnings. In the past decade, there have been more natural disasters that have caused at least US $1 billion in damages than in any previous decade. In the past year alone, the world's economy has suffered over an estimated US $89 billion in losses from natural disasters, which have claimed over 32 000 lives. The impacts from many storms would have been much greater had they not been so well forecast. Using computer models, many storms can be predicted well ahead of time, helping to mitigate their impacts. Rescue and relief operations witnessed around the world have been impressive and have contributed greatly to reducing the effects of severe storms.

1. INTRODUCTION

From fall through to winter and well into spring, extratropical storms dominate the weather outside of the tropics. Although mid-latitude cyclones can be present at any time of the year, they are most severe in the winter. They move generally from west to east across the oceans and continents.

The extratropical storm's centre is an area of low atmospheric pressure with winds going counter-clockwise in the Northern Hemisphere and clockwise south of the equator. The winds pull cold air from polar regions toward the equator and bring warm air toward the poles The clash of warm and cold air leads to widespread precipitation An extratropical storm has a narrow region called a "dry slot" spiralling into the storm's low pressure centre from the north. This intrusion of dry air is within a cold air mass astride warm moist air on the storm's east and south sides. The temperature difference between the two air masses intensifies the storm. A cold front marks the leading edge of the advancing cold air on the storm's western side, while the warm front leads the warm air's move north along and into the storm's eastern side. Thunderstorms can develop along or ahead of the cold front but do not surround the system's centre as in a tropical cyclone.

Large-scale extratropical storms are responsible for a variety of summer and winter weather. In winter, they are the major cause of blizzards, freezing rain and heavy snowfall. In summer, they can cause intense rainfall activity over wide-spread areas, spawn tornado families and produce numerous hailstorms. The impact of an extratropical storm can be from either a series of events causing cumulative effects due to a change in atmospheric circulation or from one single event.

This paper is a review of a sampling of severe extratropical storms that occurred in various parts of the globe in the 1990s. It demonstrates both the impacts of a single event and the cumulative effects of these storms.

2
EXTRATROPICAL WINTER STORMS

Various types of severe winter weather are the direct result of conditions associated with each portion of a mature, mid-latitude cyclone The strong winds and cold air behind the cold front produce severe wind-chill. Blowing snow and high wind-chill factors are the main components for blizzard conditions. Heavy precipitation over widespread areas, in the form of snow, sleet and/or freezing rain, is found along and north of a warm front to the east of a low pressure cell. The storms can move at up to 80 km/h in the developing stages or can stall in the mature stages, often depositing large amounts of precipitation in their wake.

2.1
THE STORMY ATLANTIC - 1990

During January and February of 1990, the North Atlantic bred a number of very intense storm systems that struck northern Europe with hurricane-force winds. These winter storms favoured a track across the northern and central Europe, in contrast to the usual branch pattern over the Mediterranean Sea and the North Sea. Storms penetrated well into Europe in the absence of any blocking anticyclone. The first major storm was actually traced back to a frontal system that crossed the United States of America from 18 to 21 January. The storm ultimately deepened to 948 mb over the North Sea, just east of England, on 25 January. Winds of up to 200 km/h lashed Britain, paralysing all transportation and knocking out power and phone services to hundreds of thousands of households and offices. Winds downed trees, blew roofs off buildings, and knocked over trucks, causing an epic traffic jam during the London evening rush hour. At least 45 deaths in Britain were blamed on the storm, with an early damage estimate placed at US $1.33 billion. The storm winds also caused destruction elsewhere in Europe, with a total of 93 deaths.

Only four days later, on 29 January, a second storm struck southwestern England, toppling trees and causing landslides and floods. A third major storm struck on 3 and 4 February leaving a trail of destruction over much of northern Europe. The latter was one of France's worst storms in recent decades; high winds killed 23 people and injured dozens more. The windstorm lashed Germany on the morning of 4 February, killing 7 and injuring more than 50 It uprooted thousands of trees and tore off hundreds of roofs.

The last of the major storms to strike Europe hit on 26 and 27 February. Winds of up to 160 km/h struck the Welsh coast, and winds nearly as strong assaulted the continent. In Austria, winds damaged 4 million m^3 of trees, nearly a quarter of the annual timber harvest. In Germany, the tree damage reached 64 million m^3, more than twice the average annual number of trees normally cut-down. A total of 63 fatalities occurred across Europe. In addition, at least 25 forest workers died in accidents during the clean-up effort.

2.2
THE "STORM OF THE CENTURY" — 1993

The winter storm that hit the East coast of the United States of America on March 13, 1993 was termed the "Storm of the Century" by the media. Heavy snow and strong winds covered a very wide area, breaking dozens of monthly snowfall and daily minimum temperature records from the Gulf Coast to New England

The storm experienced an explosive drop in central pressure, from 1000 mb on the morning of 12 March in the western Gulf to 960 mb over Chesapeake Bay on the evening of 13 March. As the storm swept over the Gulf Coast, it lashed Florida with a 2.7 m storm surge, similar to a hurricane, and 176 km per hour winds. The following day Richmond and Norfolk, Virginia, and Washington, D.C all reported record low pressures of 951 mb.

The effects were felt from Cuba to Canada, with a total death toll of 243 In addition, 3 million people were left without power and thousands more were isolated by record snowfall. The storm caused US $1.6 billion in insured property damage and, at the time, was the most costly non-tropical storm on record and the fourth costliest U.S. catastrophe.

It was the first time a single snowstorm closed each major airport on the East Coast of the U.S.A. Cities from Boston to Washington received 18 to 30 cm of snow. Not far inland, snow depths exceeded 30 cm from Alabama through the Appalachians and Piedmont to Canada. Mountainous areas of Maryland, West Virginia and North Carolina reported over 100 cm of snow, while locations with the lake effect exceeded 60 to 90 cm. Syracuse's 109 cm was the greatest single daily snowfall since records began in 1902. Snow fell as far south as the Florida panhandle. Birmingham, Alabama set records for 24 hour snowfall (33 cm), single storm snowfall, monthly snowfall, and snow depth!

The bitter cold that followed the storm, broke or tied at least 68 low-temperature records on Sunday, March 14 and another 72 on Monday. The Sunday low temperature of -6°C at Mobile, Alabama not only broke the daily record by 13°C but also set the March record.

The impacts from the storm would have been much greater had it struck during the week and not been so well forecast. The National Weather Service forecasters, using computer models, predicted this storm of historic magnitude at least two days in advance. On 11 March the National Meteorological Center map showed the location of the storm 48 hours ahead.

2.3 CALIFORNIA WINTER STORMS — 1995

During January and March of 1995, much of California was struck by extremely heavy precipitation from frequent Pacific storms, causing extensive property damage and loss of life Estimates show that over US $3 billion in damages and 27 lives were claimed by widespread river flooding and mud slides. The American Red Cross estimates that over 10,000 homes were damaged or destroyed. In January alone, over 762 mm of rain fell on parts of northern and central California.

A much stronger than normal Pacific jet stream was displaced well south of its normal position during much of the winter and early spring of 1995. This funnelled moisture and major storm systems directly into California. The jet core and the average storm track were displaced 15 to 20° south of the normal locations during January. During the winter of 1995, the state was struck repeatedly by very strong systems loaded with Pacific moisture.

Numerous studies have noted that a moderate-to-strong El Niño event, such as occurred the winter of 1995, usually results in a stronger than normal Pacific subtropical jet stream and a very active storm track along its path. This, in turn, creates above normal precipitation in areas along the path of major storm systems. During the winter of 1995, this storm track was the major influence in steering the strong storm systems in California.

The January storms resulted in 42 California counties being declared federal disaster areas. By late March, all 58 counties in California qualified for federal disaster assistance. Pacific Gas and Electrical reported electrical outages for 1.4 million customers during January and 1.2 million during March. Thunderstorms, sometimes severe, accompanied many of the storm systems. In both months, flooding on many of the smaller streams was caused by very heavy precipitation during short time intervals, with amounts that sometimes exceeded 100 year 24 hour event records. Then, flooding on larger rivers resulted as they were fed by overflowing tributaries. The Salinas River at Chular reached a peak flow nearly double the previous record set in 1983. The Russian River swelled to almost 5 m above the flood stage. All-time high-water marks were set in many parts of Southern California

The January storms affected northern California more severely while the March storms were concentrated more on central California. However, both months showed much above normal precipitation over most of the state. Since most of the storms occurred within relatively cool, unstable air masses, much of the precipitation above 1 525 m in elevation fell and accumulated as snow. This somewhat lessened the immediate impact of the storms in terms of flooding. The water content of the snow pack exceeded 150 per cent of normal for the

Sacramento Basin and Sierra Nevada mountains by the end of March. Some locations reported snow depths exceeding 12 m by late March.

One of the obvious impacts of unusually heavy precipitation was on agriculture. The inability to either harvest or plant severely affected many crops. Thousands of acres of Monterey County farmland were flooded. Over 3 000 people, mostly farm workers, had to be evacuated from the town of Pajaro, which was entirely flooded due to a levee break.

2.4
ICE STORM '98

Ice storms are common to the eastern provinces of Canada and the eastern states of the United States. Approximately 15 occur each year and last from a few hours to more than a day. Usually these systems fade away or are followed by a warming trend that melts the ice and alleviates any cause for concern.

The Ice Storm of January 1998 was the worst to ever hit Canada and the United States, due to the amount of ice accumulation, the duration of the storm and the population affected. Areas affected were eastern Ontario, southern Quebec, southern New Brunswick, upstate New York, northern New England, and some parts of Nova Scotia. The water equivalent of the freezing rain and ice pellets exceeded 100 mm in many areas, more than twice the yearly average.

Freezing rain coated every exposed surface with such a thick layer of ice that tree branches snapped off, trees fell down, hydro wires and towers were destroyed and all types of transportation and travel were seriously affected. The storm claimed at least 25 lives and severely inconvenienced millions. At the height of the storm, nearly 3.5 million people were without electricity or heat. Thousands had to take refuge in shelters. Falling temperatures and additional snowfall continued to hamper relief efforts after the storm. A week after the storm ended, nearly a million people were still without light or heat. The estimated costs relating to the ice storm were close to US $1.4 billion.

A northeast outflow of air, with temperatures below 0°C, from a high pressure area over Hudson Bay and northern Quebec, pushed southward to lie north of Lake Ontario by 5 January. At the same time, a weak southerly flow of warm air was being pushed into southern Ontario and southern Quebec.

This weather pattern set up the freezing rain, as warm air was forced to rise gently over denser cold air. Rain falling from the warm air mass cooled to below the freezing point as it passed through the cold air below. Super-cooled raindrops froze on contact with any cold surface in the cold air mass and ice began to accumulate.

Environment Canada played an important role in a wide range of federal support efforts related to the ice storm. Throughout the crisis, Environment Canada was able to provide Canadians with accurate and timely weather warnings and information on a 24-hour basis. The department also provided utilities, municipalities, provincial authorities, other federal departments and emergency response officials with extensive specialized weather support, as well as advice and assessments on a broad range of environmental issues related to storm damage. Meteorologists and climate experts handled over 1 000 media calls and visits to the department's national web site increased by 50 per cent to over 300 000 hits a day.

1.5 million households were without power and 100 000 people took refuge in shelters. Trees and power lines were falling and roads were blocked, which making travelling conditions hazardous. More than 22 deaths were directly attributed to the Ice Storm. As people were reluctant to vacate their homes, many were stricken with hypothermia.

3.
SUMMER EXTRATROPICAL STORMS

Various types of severe summer weather are the direct result of conditions associated with each portion of a mature, mid-latitude cyclone. In summer, flooding is the major threat from extratropical storm activity. The storms produce both widespread, heavy precipitation ahead of a warm front and intense, localised rainfall (from thunderstorm activity) in front of, on the leading edge, of a cold front. Another major threat is posed by thunderstorm activity. If severe enough, it can produce multiple hailstorms and families of tornadoes dispersed over a large area.

3.1 THE GREAT FLOOD - 1993

The great flood of 1993 in the United States surpassed all floods experienced in living memory in terms of precipitation amounts, record river stages, the extent of the flooding, persons displaced, crop and property damage and flood duration.

During the spring of 1993, the record and near-record precipitation, on soil saturated from the previous seasonal precipitation, resulted in flooding along many major river systems in the Midwest, including the Mississippi and Missouri and their tributaries.

Prior to these excessive rains, however, the region was ripe for flooding as a result of above normal precipitation that was persistently observed through most of the region beginning in July 1992, generating waterlogged ground and high stream flows and reservoir levels. There had been excessive winter snow pack in the Rocky Mountains, saturated soil conditions in the Midwest and critical run-off conditions. As a result, long-term moisture surpluses occurred across a large portion of the east-central Great Plains and the middle Mississippi Valley. For some locations, rainfall totals amounted to an extra year's worth of rain over 14 months.

By March 1993 the soil remained soaked and rivers remained high, despite slightly dry conditions. United States National Weather Service hydrologists in Minneapolis alerted residents of the upper Mississippi Valley to the saturated ground on 3 March, 1993. By the end of March, the National Weather Service released a warning that widespread, serious flooding could occur in the Northeast if an extended period of warm weather was accompanied by significant rainfall. The entire eastern half of the United States faced an above average flood risk.

From April to June, the upper Mississippi Valley received an average of 410 mm of rainfall, making these three months the wettest period since records began in 1895. The average precipitation for the period is 280 mm. Wet fields delayed or prevented spring planting. Streams and rivers began to fill. With the ground unable to absorb more rain, the water flowed southward down the Mississippi toward the Gulf Mexico.

Heavy rain fell from 19 June to 21 June, concentrating on southwestern Wisconsin, southern Minnesota, southeastern South Dakota, and Iowa. Serious flooding began on the tributaries of the upper Mississippi, as well as the river itself.

An estimated 1 100 levees or floodwall failures occurred during the summer of 1993 — 70 per cent of the total number of levees along the affected rivers. The first failure came on 20 June, when, despite efforts to reinforce the levee with sandbags, the Black River broke through, flooding approximately 100 homes in Black River Fall, Wisconsin. Residents and volunteers from around the world had shovelled more than 417 million kg of fill into 26 million sandbags by the end of the summer. Despite their efforts, flood waters washed over an estimated 4 million hectares in the Mississippi River Basin, destroying or seriously damaging more than 40 000 buildings. The flood killed at least 47 people.

The flood water moved down the Mississippi from St. Paul, joined by water from tributaries in southern Minnesota, Wisconsin, Iowa, and northern Illinois. Similar waves of flood water were also flowing southward on the Des Moines and Missouri rivers, heading for the Mississippi.

Flooding was aggravated when a heavy rain fell from 25 June through to 27 June on Iowa, Missouri, and southern Illinois, adding to the water already moving down the Mississippi and other rivers. During late June and July, 305 to 457 mm of rain fell across the central part of the country. By mid-July, the US National Weather Service announced that 100 rivers were over their banks, with 14 at their highest level ever recorded.

At the beginning of the summer of 1993, the mean position of an unusually strong jet stream was dipped southward over the northern portion of the Mississippi basin, oriented south-west to north-east between the persistent low-pressure trough to the north-west and an unusually strong Bermuda High over south-eastern United States. The clockwise winds around this high-pressure area pumped humid air from the Gulf of Mexico northward along the Mississippi Valley. The high pressure also helped block an eastern movement of thunderstorm clusters from the Midwest. The unusually large contrast between low and high pressure helped to create stronger southerly winds, which brought in moistureladen air causing record-breaking rains. The boundary between cool air and warm air remained over the upper Mississippi Valley. Warm, humid air flowed over the cool, dry air, which helped to create thunderstorms. The influence of the sea surface temperature anomaly in the tropical Pacific associated with the El Niño/Southern Oscillation (ENSO) phenomenon was also a contributing factor.

The combination of these circumstances resulted in the worst flooding in over a century in the northern Mississippi basin. Record flooding occurred at nearly 500 forecast points in a nine state region and, in some cases, surpassed old record stages by nearly 2 m. The duration of the flood was overwhelming, by 1 September 1993, some towns had experienced 153 consecutive days of flooding. The flooded region finally began drying out in early August when the upper-air pattern changed, bringing unseasonably cool and dry weather to the Midwest.

The expected return period for an event of this magnitude was calculated from precipitation probabilities. For most sites in the midwestern United States, the recurrence interval was in the 500 to 1 000 plus year range. The presence of such extremely long return periods dramatically indicates the extraordinary nature of the event.

The duration and magnitude of the flood strongly support the premise that this event was a significant climate variation. It is quite possible that one or more climate-driving forces, such as the El Niño/Southern Oscillation (ENSO) phenomenon, significantly contributed to climate variation.

3.2

PALM SUNDAY TORNADO OUTBREAK, 1994 AND THE MIDWEST TORNADO OUTBREAK, 1999

Severe thunderstorms spawned 27 tornadoes in the southeastern United States on Palm Sunday 27 March 1994. The deadliest storms occurred in Alabama, Georgia and the Carolinas. This was the deadliest tornado outbreak since May 1985, killing 42 people and injuring more than 350. With 59 tornadoes, including two tornadoes measuring F4 on the Fujita Scale, March was an above average month for the United States and total damages were estimated at US $217 million.

On that morning, a cold front curved from Ohio through central Tennessee to a low-pressure centre along the Texas coast. The front moved into northern Georgia and Alabama, then stalled while the low pressure moved along the front into central Alabama. Southerly winds exceeded 48 km/h ahead of the front, where temperatures rose above 21°C (including a record 28°C in Atlanta). In widespread heavy rain behind the front, temperatures were only in the 10-20°C range. Just a thousand metres above the ground, 97-113 km/h south-to-southwest winds brought in Gulf air. Higher up, west-to-southwest winds exceeded 160 km/h. The warm, moist Gulf inflow and the unusually strong winds favoured destructive tornadoes. Strong winds aloft steered the severe thunderstorms northeast, along and ahead of the cold front.

The most powerful and deadly tornado, an F4, touched down south of Ragland in northeastern Alabama, just before 11 a.m. The tornado destroyed houses and threw cars across the state highways. High winds shattered the windows of a church and ripped off its roof causing a brick wall to collapse, killing 20 people and injuring another 92. The tornado headed northeast to the Georgia line just before noon, having caused US $50 million in damage. Meanwhile, an F2 tornado south of Guntersville, Alabama injured 20 people and damaged over 100 houses, and an F3 tornado east of Oak Grove grew to over 800 m wide and injured 20 people.

That afternoon, the mayhem reached Georgia. A tornado picked up a mobile home and carried it 23 m, killing the elderly couple inside. Over Floyd County, the sky turned green-black by 1 p.m. Within ten minutes, severe thunderstorms hurled hailstones up to 10 cm in diameter with continuous lightning near Cave Springs. The thunderstorms shortly spawned an F4 tornado that travelled almost 80 km, killing 3 people and injuring 20. The tornado grew to over 1.6 km wide, destroying nearly 40 chicken houses and killing more than half a million chickens. Hundreds of thousands of trees were levelled, with 18–24 m pines uprooted.

An F3 tornado touched down northwest of Dawsonville, Georgia later that afternoon and travelled over 70 km, killing 3 people and injuring 45. This tornado also killed more than half a million chickens and downed hundreds of thousands of trees. It grew up to 2.4 km wide in White County. Damage was estimated at US $17 million.

At Dahlonega, an F3 tornado tracked 37 km, killing 3 people and injuring 15 as it reached 1.2 km in width and caused US $3 million in damages. The skies of Rome were tainted a green-black colour as well. In five minutes, thunderstorms whipped gusts up to 140 km/h. Another F3 tornado then touched down south of Adairsville, at 3 p.m., and travelled 64 km, killing 9 and injuring 7. Among the US $12 million in damages were more than 300 000 chickens. The tornado was 2.4 km wide in hilly Pickens County. In Hill City, it tossed a mobile home over 90m, killing all six of the family inside. The tornado was still 1.2 km wide as it climbed a plateau toward nearby Burnt and Sassafras.

An F3 tornado northeast of Clarksville, Georgia crossed into South Carolina, injuring 35 people. Up to 1.6 km wide, it descended a 150 m cliff to the base of Tallulah Falls. Some of the debris blown into the gorge was from as far as Piedmont, Alabama, more than 225 km away.

An F2 tornado north of Helena, Alabama at 5.30 p.m. injured 53 people before lifting near Meadow Brook, prefacing another round of violent storms. An F2 tornado touched down northwest of Cedartown, Georgia at 7 p.m. and travelled 34 km, injuring 30 people and causing US $7 million in damages. The tornado flattened trees on the Booze Mountain on its way to Lindale, a suburb of Rome where residents had already seen the green-black skies and continuous lightning about five minutes before. The skies roared as the tornado passed overhead while paralleled by a weaker twister about 800 m away.

The outbreak of significant tornadoes across the southeast United States on Palm Sunday was not as synoptically evident as many of the outbreak cases in the past. The outbreak occurred without the presence of a well defined surface low centre or a prominent short wave trough. Nevertheless, what did evolve into a favourable configuration for the formation of supercells and strong tornadoes were the warm sector air mass characteristics, particularly the wind fields.

A more recent tornado outbreak occurred across the midwestern United States earlier this year. Powerful storm systems pushed across Oklahoma, Kansas and Texas on the evening of 3 May 1999, spawning 76 tornadoes, obliterating towns and killing 44 people while injuring 900 others. About 4 180 homes and businesses were destroyed or heavily damaged. The tornadoes knocked out power to thousands of people.

One unusually large and powerful F5 tornado formed just outside Oklahoma city, killing 38 people and injuring hundreds as it moved north and east with winds topping 418 km/h, cutting a path over 800 m wide. The storm carved a 30 km gash through the area demolishing about 2 000 homes About 240 km north, a tornado spawned by the same storm system tossed mobile homes, damaged houses and killed at least five people while injuring over 80 others in Wichita, Kansas.

At least 6 tornadic storms developed over a 5-hour period on the Monday evening, mainly in central and north-east Oklahoma. Cars were tossed across highways and crushed. Houses were smashed into piles of splintered timbers and brick The ground was scoured bare in places and stripped of trees. The estimated damage was in the hundreds of millions of US dollars. Several tornadoes may have been 1.6 km wide with winds up to 420km/h, measuring an F4 on the Fujita scale.

Eleven counties in Oklahoma and one in Kansas were declared federal disaster areas. five people were still missing in rural Oklahoma two days following the devastating tornado outbreak. A cold rain fell as residents began to pick through the wreckage of their homes and bulldozers were brought in to clear away debris.

3.3 SAGUENAY RIVER FLOODING — 1996

Another type of flooding event, the flash flood, was exemplified by the Saguenay River flooding in 1996. One July weekend, torrential rains gave rise to one of the worse flooding events in Canadian history. The floods left at least 10 people dead, 1 350 homes destroyed, while 16 000 people had to be evacuated from their houses. Material losses were estimated at almost US $545 million, making this one of Canada's most costly natural disasters.

The morning of 19 July 1996, a low pressure system located over southern Ontario was on the verge of rapid and intense development In the following 24 hours, the system intensified as a fall-like low pressure system as it moved towards the Quebec — New Brunswick border before slowing down and becoming almost stationary over the mouth of the St. Lawrence River. The largest zone of accumulation occurred just south of the Jonquière-Chicoutimi-La Baie area of the Saguenay Valley, where in excess of 200 mm of rain fell, most within a 36 hour period. Rainfall amounts were also impressive in Saguenay-Lac Saint-Jean and Parc-des-Laurentides areas on the northern shore of the Saint-Lawrence River, west of Sept-Iles. Over these areas, the topography and wind circulation generated from the storm produced locally higher rainfall amounts due to lifting. The decline of the low pressure system over eastern Quebec allowed the precipitation area linked with this system to persist over the most affected areas.

The Saguenay floods caused extensive erosion along some major river reaches resulting in major channel widening and bank erosion, breaching of dams and dykes and damage to bridges and roads.

Many precipitation records were established during this weekend. For many sites across the province of Quebec, the total rainfall amounts from the storm exceeded the amounts that normally fall during the month of July. The 18 July to 21 July 1996 torrential rains were the most extreme, in intensity and area, for the province of Quebec in over a century.

3.4
YANGTZE RIVER FLOODS — 1998

The summer flooding of 1998 in China killed 4 150 people as heavy rains inundated the Yangtze River Valley for more than 60 days. The floods affected 223 million people (1/5th of the population of China), inundated 25 million hectares of cropland and cost US $30 billion in damages, making it the most costly disaster of 1998 and causing the worst flooding in over 44 years. The flooding caused severe damage to critical facilities such as health clinics, schools, water supplies and other infrastructure such as roads, bridges, and irrigation systems, as well as industrial facilities. During June and July, locations near the Yangtze River reported over 750 mm of rain, with isolated amounts greater than 1 270 mm.

The cause of the disaster was excessive rainfall (which according to Chinese meteorologists was ascribed to the worldwide El Niño phenomenon followed by La Niña); the melting of lasting and deep snow accumulated in Qinghai — the Tibet plateau in southwest China; a weak Asian monsoon; unusual sub-tropical high pressure systems on the west Pacific Ocean; and a decrease in the number of typhoons.

Though heavy summer rains are common in southern China, the Yangtze River Basin has lost 85 per cent of its forest cover from logging and agriculture in recent years, leaving many steep hillsides bare and causing rainfall to run quickly into the river rather than being absorbed. This has led to more devastating landslides and floods. The heavy damming of the river has greatly increased the speed and severity of the resulting run-off. At the same time, growing population pressures have led many to settle on vulnerable flood plains and hillsides, now increasingly inhabited. The frequency of floods has increased from once every twenty years in earlier centuries to nine out of ten years.

Given the magnitude of the disaster, which was unprecedented over the last few decades, the rescue and relief operations mounted by the Chinese Government at all levels were impressive. The massive mobilisation of farmers and villagers by the police and army reduced the suffering and loss of human lives. The Government provided emergency relief efficiently and effectively.

China's advanced prevention policy, based on timely predictions, forecasting, and early warnings, greatly contributed to mitigating the outcome of the flood The State Council of China has recognized the role of human activities in worsening 'natural' disasters. It has banned logging in the upper Yangtze watershed, prohibited additional land reclamation projects in the river's flood plain and has earmarked US $2 billion to reforest the watershed.

3.5 THE SYDNEY HAILSTORM — 14 APRIL 1999

A severe thunderstorm, which struck the eastern suburbs of Sydney, Australia on 14 April, 1999 caused extensive damage estimated at US $1 billion, making it possibly Australia's most costly natural disaster. The storm's damage surpassed that of the Newcastle earthquake of 1989 and Tropical Cyclone Tracy of 1974 in Darwin. The storm tore across the city overnight, damaging thousands of homes and cars, cutting power supplies and phone lines and briefly grounding planes Plummeting chunks of ice damaged roofs, battered cars, and knocked out traffic lights. Up to 15 000 homes lost power. Lightning sparked at least 25 electrical fires. Dozens of people were treated for cuts from broken glass and other injuries. Others were injured the following day as they tried to make repairs.

The storm was highly unusual in meteorological terms Not only did it produce hailstones up to 9 cm in diameter, but it occurred at a time of year when severe thunderstorms are normally rare. The storm took a highly unusual track, moving from land to sea, back to land, and finally out to sea, lasting a total of $5^1/_2$ hours.

A thunderstorm began to form about 115 km to the south-southwest of Sydney in the late afternoon. The storm subsequently developed into a supercell, a rare but unusually severe type of thunderstorm whose structure, behaviour, intensity and longevity is quite different to ordinary thunderstorms. By about 6 p.m., the storm moved up the New South Wales coastline with the western edge producing substantial amounts of hail in the Wollongong area. The storm then moved out to sea but continued to track north-northeast, parallel to the coast, before crossing inland again near Helensburgh. As the storm neared Sydney, it split into 2 sections. The weaker of the two cells moved out towards the sea and the stronger cell moved on towards the city centre. Lightning, thunder and rain was reported around the inner city areas of Sydney. The storm continued on to devastate Sydney's eastern suburbs. The storm eventually moved out to sea and had dissipated by 10 p.m.

The storm was triggered by a relatively warm autumn day that saw temperatures peaking at 26.2°C, about 2°C above normal. As the warm air rose, it carried large amounts of moisture high into the atmosphere where it met cold air, causing the vapour to suddenly freeze.

No public severe weather warning was issued for the Sydney hailstorm. The Australian Weather Bureau had been expecting a storm that would probably produce small hailstones but when it failed to occur by 3.30 p.m., they downgraded the probability of it hitting the city at all. Forecasters expected that the upper winds would steer any thunderstorms from the south of Sydney to the north-east and out to sea. They never envisaged that any thunderstorms that might occur would produce such severe weather. The storm had been drifting out to sea but caught the Australian Weather Bureau by surprise when it suddenly cut inland.

All units of the State Emergency Service were sent out to assess the disaster situation and to start the necessary repairs. Several days into the storm clean-up, a windstorm hit the area, bringing rain and 100 km/h plus winds that damaged some of the emergency repairs

4. CONCLUSION

The 1990s have seen an increase in the cost of natural disasters resulting from extratropical storm activity, both in terms of financial costs and human lives, despite improvements in risk forecasting. While El Niño and other phenomena may intensify weather conditions, the greater problem may be that more people are living in vulnerable areas and take insufficient precautions despite great advancements in public safety warnings. In the past decade, there have been more natural disasters that have caused at least US $1 billion in damages than in any previous decade. In the past year alone, the world's economy has registered over an estimated US $89 billion in losses from natural disasters, while claiming over 32 000 lives.

The impacts from many storms would have been much greater had they not been so well forecast. Using computer models, many storms can be predicted well ahead of time, helping to mitigate the impacts. The accuracy in forecasting has improved significantly over the years. There is now the potential to predict storms well ahead of time, helping to mitigate the impacts. The quality of a 48-hour forecast in 1999 has surpassed that of the 36-hour forecast in 1990. As well, today's meteorologists are now issuing 120-hour forecasts with the same accuracy as the 96-hour forecasts from the beginning of the decade.

Rescue and relief operations launched around the world have been impressive and greatly contributed to reducing the effects of severe storms.

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