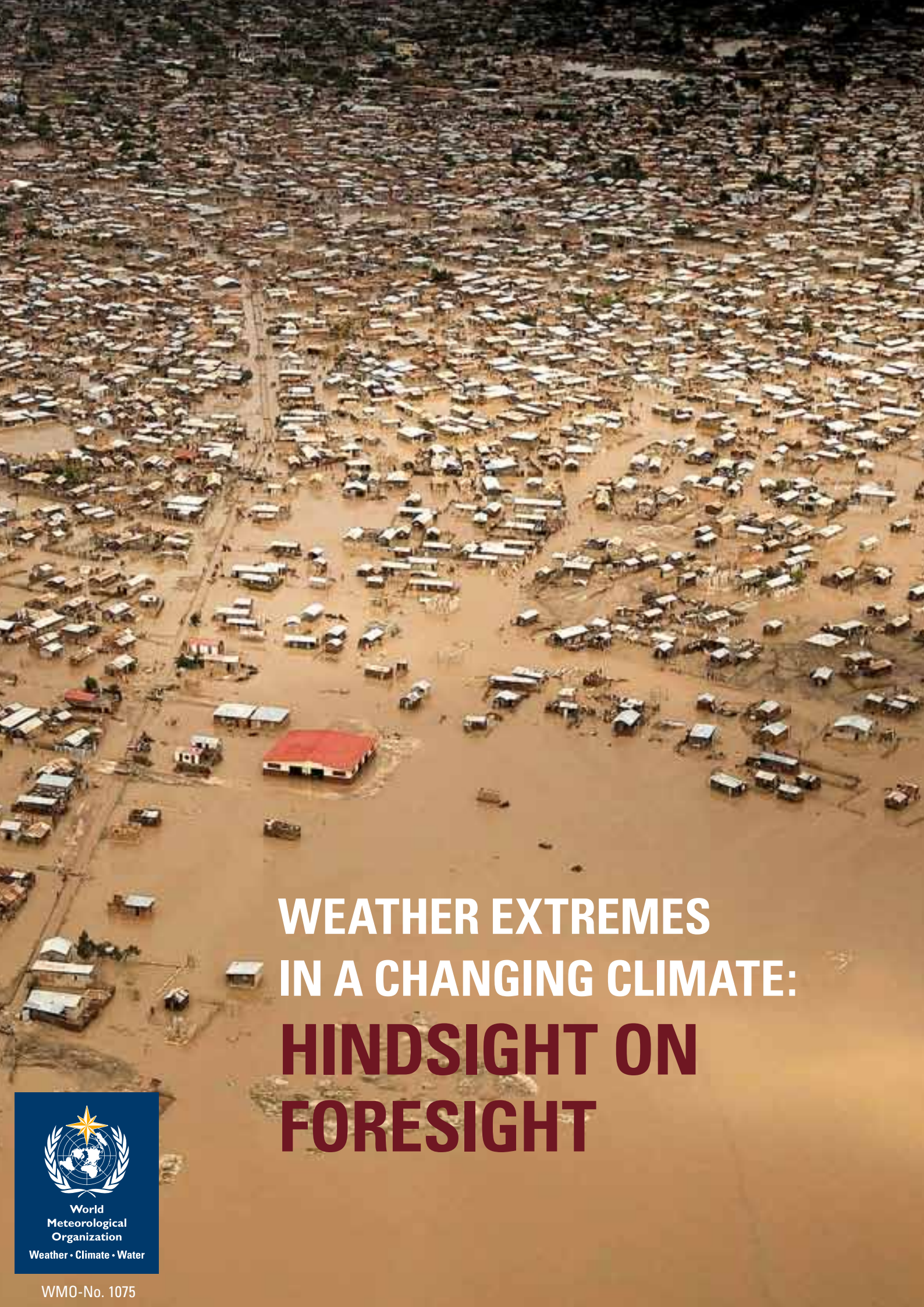




WEATHER EXTREMES IN A CHANGING CLIMATE: HINDSIGHT ON FORESIGHT



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WEATHER EXTREMES IN A CHANGING CLIMATE

Devastating climate and weather-related events recorded in recent years have captured the interest of the general public, governments, and media. This brochure provides a sample of extreme events for the past decade (2001–2010). Some of these events compared with — or exceeded in intensity, duration or geographical extent — the most significant historical events.

The facts in this brochure are drawn from the World Meteorological Organization (WMO) annual *Statements on the Status of the Global Climate*. These summarize global and regional temperature trends and extreme weather events with high socio-economic impact. The statements review temperature, precipitation, severe storms, tropical cyclones and the evolution of snow cover and polar ice.

This brochure also includes reflections on climate predictions, drawn from assessment reports of the Intergovernmental Panel on Climate Change (IPCC), a body established by WMO and the United Nations Environment Programme (UNEP).

Scientists are still studying the quantitative links between these events and climate change. Meanwhile, this brochure illustrates a qualitative fit between the facts observed about extreme events over the past decade, and the IPCC projections regarding the consequences of climate variability and change.

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EXAMPLES OF RECENT WEATHER EXTREMES

2001–2010

This compilation, drawn from annual WMO *Statements on the Status of the Global Climate*, gives examples of the many weather extremes over the past decade.

2001: End of long-running La Niña episode which influenced temperature and precipitation in many parts of the world. Extreme cold temperatures in Mongolia and the Russian Federation, with minimum temperatures of near -60°C across central and southern Siberia for two weeks in January. Alaska recorded warmest winter on record. Canada recorded the eighteenth straight warmer-than-average season.

2002: Return of El Niño. Exceptionally heavy rains in central Europe (including Germany, the Czech Republic, Austria, Romania, Slovakia) caused flooding of historic proportions, killing more than 100 people and forcing the evacuation of more than 450 000 people. Damage was estimated at US\$ 9 billion in Germany alone.

2003: India, Pakistan and Bangladesh witnessed exceptionally harsh pre-monsoonal heat waves. Continental Europe had the hottest summer since at least 1540. Europe recorded in August 2003 its worst heatwave. In many locations, temperatures rose above 40°C. In Belgium, France, Germany, Italy, the Netherlands, Portugal, Spain, Switzerland and the United Kingdom, 40 000 to 70 000 deaths were attributed to the heatwaves. In the European Alps, the average thickness loss of glaciers reached the equivalent of about three metres of water, nearly twice as much as during the previous record year of 1998. The heatwaves resulted from strong high pressure over western Europe related to a marked ridge of high pressure in the large-scale upper atmospheric wind flow.

2004: Widespread winter storms in the Mediterranean region. Extreme hot conditions persisted in Japan during the summer, with record-breaking temperatures. A record number of 10 tropical cyclones made landfall in Japan (the previous record was six), including Typhoon *Tokage*, the deadliest to hit Japan since 1979. In March, the first tropical cyclone since the start of satellite records made landfall on the southern coast of Brazil. In Afghanistan, drought conditions that had plagued the country for the past four years continued in 2004. In spring, parts of the north-east People's Republic of China experienced the worst drought conditions since 1951, and southern China received the lowest autumn rainfall since 1951.

2005: 2005 ranked in the top two warmest years along with 1998. The 2005 Atlantic hurricane season was the most active season on record. An unprecedented 27 named tropical storms, including 14 hurricanes, caused devastating losses across Central America, the Caribbean and the United States of America. Seven of these were classed as "major" hurricanes (category 3 or higher on the Saffir-Simpson scale). In Central America and the Caribbean region, the most damage occurred from Hurricanes *Dennis*, *Emily*, *Stan*, *Wilma* and *Beta*. In the United States, Hurricane *Katrina* was the deadliest hurricane to hit the country since 1928,



killing over 1 300 people, mostly in the southern states of Louisiana and Mississippi. Hurricane *Wilma* was the most intense Atlantic hurricane ever recorded. Long-term drought continued in parts of the Greater Horn of Africa, including southern Somalia, eastern Kenya, south-eastern Ethiopia, and north-eastern United Republic of Tanzania and Djibouti, with 11 million people at risk of starvation. In Brazil, the state of Amazonas experienced the worst drought in nearly 60 years, resulting in record low water levels in the Amazon River. In October, drought conditions extended further south into neighbouring Paraguay. By the end of the year, drought affected much of the central United States from the southern Great Plains to the western Great Lakes. Australia officially recorded its warmest year on record, with data indicating that the annual mean temperature was 1.09°C above the standard 1961–1990 average.

2006: Heavy rains ended prolonged drought in the Greater Horn of Africa, leading to the worst flooding in October/November in 50 years. Drought in many parts of the United States led to the worst wildfire season on record. Disastrous tropical cyclones hit some south east Asian nations, including Typhoon *Durian* which killed nearly 1 200 people in the Philippines.

2007: Nome in Alaska was frost-free from June to September – its second longest frost-free season on record. Exceptionally heavy rains in a number of African countries (Burkina Faso, Sudan, Uganda) caused widespread flooding. Mexico suffered the worst flooding in five decades in November, causing the worst weather-related disaster in its history. Severe to exceptional drought continued in the south-east United States, with the driest spring on record and the second worst fire season after 2006. Australia suffered a sixth straight year of drought in Murray-Darling Basin. In 2007 sea ice extent reached its lowest September value since the beginning of measurement in 1979.

2008: China witnessed the worst severe winter weather in five decades in January, with over 78 million people affected by the freezing temperatures and heavy snow. The exceptional cold extended westwards across Asia as far as Turkey. There was an unusually mild winter over most parts of Scandinavia; with monthly anomalies exceeding 7°C for much of Norway, Sweden and Finland, it was the warmest winter ever recorded. Tropical Cyclone *Nargis* with maximum winds of 215 km/hour was the most devastating cyclone to strike Asia since 1991, causing Myanmar's worst natural disaster ever. Heavy rain and flooding in Brazil in November affected 1.5 million people and resulted in 84 fatalities. Severe prolonged drought hit Argentina, Uruguay and Paraguay, where large areas reported one of the driest years on record.

2009: Australia was marked by exceptional heatwaves, which affected the south-eastern part of the country in January/February. This was associated with disastrous bushfires that caused more than 170 fatalities. Victoria recorded its highest temperature with 48.8°C at Hopetoun, the highest temperature ever recorded so far south in the world.

2010: The year 2010 ranked as the warmest year on record, along with 1998 and 2005. (The difference in global surface temperature between the three warmest years 1998, 2005 and 2010 is within a small range of 0.02°C, making the difference statistically indistinguishable.) The 2009/2010 winter was characterized by extremely cold temperatures over large parts of the northern hemisphere, including parts of Europe, Asia and



**THE SUMMER OF 2010 WITNESSED A SEQUENCE OF
DEVASTATING EXTREME EVENTS**





Satellite images of Pakistan, 17 August 2009 (left) and 17 August 2010 (right).

North America. Hundreds of records for daily minimum temperatures were broken in the United States. Heavy snowfall disrupted air and road traffic in Europe, the United States and China. By contrast there were very mild conditions over the Arctic and Canada. These conditions were associated with large-scale atmospheric disturbances connected to the Arctic and North Atlantic Oscillations and the El Niño event.

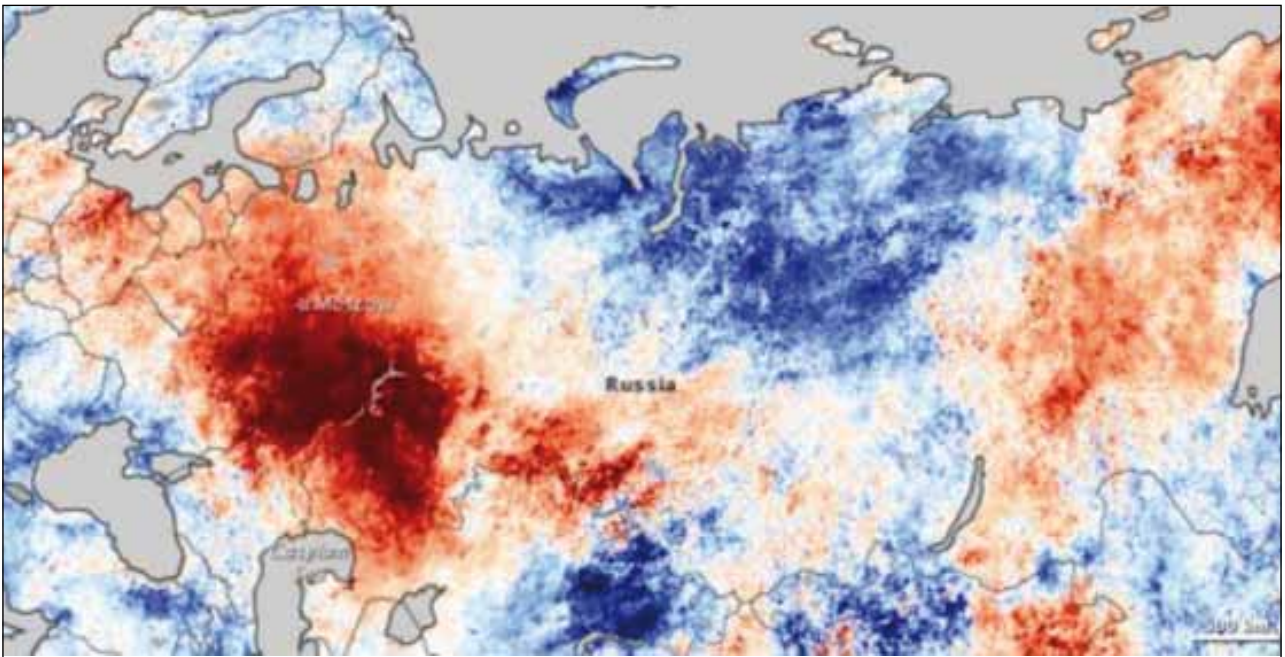
The summer of 2010 witnessed a sequence of devastating extreme events, frequently associated with unprecedented impacts. Over the course of the 2010 monsoon season, Pakistan experienced the worst floods in its history. Heavy rainfall, flash floods and riverine floods combined to create a moving body of water equal in dimension to the land mass of the United Kingdom. The floods affected 84 of 121 districts in Pakistan, and more than 20 million people – one-tenth of Pakistan’s population – devastating villages from the Himalayas to the Arabian Sea. More than 1 700 people were killed, and at least 1.8 million homes damaged or destroyed.

July 2010 was the warmest month ever in Moscow since the beginning of modern meteorological records. Temperature exceeded the long-term average by 7.8°C (the previous record in July 1938 was 5.3°C above average). More than 20 daily temperature records were broken, including the absolute maximum temperature in Moscow. The high temperatures which extended from July to the first half of August triggered massive forest and peat fires in the European part of the country, with smoke and smog adversely affecting tens of millions of people.

The devastating heatwave in the Russian Federation and floods in Pakistan were associated with a “blocking event” in the northern hemisphere jet stream, which kept weather patterns stationary over certain countries. La Niña conditions, which prevailed during summer 2010 and subsequently, have been associated historically with increased likelihood of wetter-than-average conditions over the Indian subcontinent.

In many parts of China, high temperatures broke historical extremes. Floods, landslides and mud-rock flows also caused serious economic damage. In August, Zhouqu County, Gansu Province, was hit by the most devastating flood and mud-rock flow in the country’s history of the China, killing more than 1 500 people.

Greenland recorded its warmest decade (2001–2010) since modern measurements. Most stations in West Greenland, especially in the southwest, recorded their warmest ever year in 2010. In August, ice measuring more than 200 km² calved from the Petermann Glacier in northern Greenland – the largest chunk in the past 50 years of observations and data (since 1962). Tens of thousands of icebergs calve yearly from the glaciers of Greenland, but this one was exceptionally large; because of its size, it more typically resembled icebergs in the Antarctic.



Satellite image of the heatwave of the Russian Federation (9 August 2010).

The Sahel region and West Africa were hit by extreme precipitation events. Niger, which had been gripped by prolonged drought, suffered devastation from flash floods in July. Hundreds of thousands were made homeless in Benin by flooding.

Australia faced its worst flooding in about 50 years. The year 2010 was the third wettest year for Australia as a whole and the wettest for the state of Queensland, where the floods were the most devastating.





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SNAPSHOTS: SOME EXTREME EVENTS OF 2001–2010



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EXTREME EVENTS 2001–2010



Heatwaves/
Extreme high temperatures



Severe or prolonged
droughts



Tropical cyclones/
hurricanes/typhoons



Intense storms/Flooding/
Heavy rainfall



Cold waves/Extreme low
temperatures/Snow storms

1. Extreme cold winter in Siberia and Mongolia. Minimum temperatures dropped to near -60°C across central and southern Siberia resulting in hundreds of deaths. (2001)
2. Between February and April, heavy rainfall and flooding hit the southern African countries of Mozambique, Zimbabwe, Malawi and Zambia. (2001)
3. Typhoon *Rusa* hit Korea causing flooding and hundred of deaths. It was reported as the worst national storm since 1959 and also led to a new national record of 24-hour rainfall with 870 mm. (2002)
4. Unprecedented extreme heat waves occurred across much of Europe during summer. This led to record-breaking temperatures, surpassing in some cases 40°C , and tens of thousands of related deaths. (2003)
5. Tropical Cyclone *Gafilo* hit Madagascar with winds up to 260 km/hour, causing hundreds of deaths. (2004)
6. Hurricane *Ivan* hit the Caribbean causing flooding, massive destruction and deaths. (2004)
7. For the first time in history a documented hurricane developed in the South Atlantic Ocean in March. Unofficially named *Catarina*, it made landfall along the southern coast of Brazil, causing great damage. (2004)
8. Warmest summer on record in central Canada. (2005)
9. Worst drought in 60 years in Brazil caused the lowest Amazon flow in 30 years. (2005)
10. The monsoon season brought unprecedented heavy rain and widespread massive flooding to parts of western and southern India, affecting more than 20 million people. (2005)
11. Most active Atlantic hurricane season on record. Hurricane *Katrina* hit the southern United States of America, killing more than 1300 people, and was considered as the deadliest hurricane to hit the country since 1928. (2005)
12. Typhoon *Durian* hit Philippines causing massive damages and more than 1000 deaths. (2006)
13. Long-term drought continued in the early part of the year over the Greater Horn of Africa. (2006)
14. Severe to extreme drought was present across large parts of western United States, as well as in the southern plains. Devastating fires caused massive destruction and millions of hectares burned. (2006–2007)
15. In July extreme rainfall triggered the worst flooding in 60 years over the United Kingdom. (2007)

16. Coldest winter in 50 years and unusual snowfalls in the northern part of Europe. (2007)
17. Massive flooding in Mexico in early November was the worst in the country's history. (2007)
18. Summer heavy rainfall caused flooding and flash floods in the north Indian Ocean. More than 1.5 million people were affected. (2007)
19. Tropical Cyclone *Gonu* formed in the north Indian Ocean. It was reported as the strongest tropical cyclone to hit the Islamic Republic of Iran. (2007)
20. A remarkably mild winter occurred over most parts of Europe. Large parts of Norway, Sweden and Finland had the warmest winters in decades. (2008)
21. Extreme cold temperatures combined with the wettest winter in 50 years in the United States. The extreme cold event extended as far west as the Pacific Northwest. (2008)
22. Severe prolonged drought hit Argentina, Uruguay, Paraguay and Brazil, affecting agriculture, livestock and water resources. For large parts of the region, it was the worst drought in decades. (2008)
23. Several all-time winter snowfall records were set across the United States. (2008)
24. During the September–November period, heavy rains caused severe infrastructure damage. These were the heaviest rains in the region for more than a decade. (2008)
25. In southern Australia, dry conditions reinforced long-term shortages in the agriculturally important Murray-Darling Basin. (2009)
26. Tropical Cyclone *Nargis* was the worst natural disaster in the world in 2008. It hit Myanmar, causing massive destruction and deaths. (2008)
27. An exceptional heatwave in late October/early November caused record-breaking temperatures of more than 40°C in large areas of Europe. (2009)

Note: Definitions of extreme events vary. This map includes single and/or a succession of weather phenomena leading to abnormal, high-impact meteorological and/or climate conditions, such as extreme heat, drought, flooding, etc.



large parts of southern South America. (2007)
 considered the worst weather-related disaster in the
 floods in several African countries. Thousands of homes
 re affected. (2007)
 Ocean, making landfall in Oman and then reaching the
 ggest cyclone on record in the Arabian Sea. (2007)
 of Scandinavia. With monthly anomalies exceeding 7°C,
 warmest winter ever recorded since the beginning of
 worst snowstorm in five decades across China during
 est as Turkey. (2008)
 Paraguay and southern Brazil, causing severe damage to
 areas it was one of the driest years on record. (2008)
 across Canada. (2008)
 and extended rainfall affected Algeria and Morocco,
 the worst floods in a century for Algeria. A similar
 r across the same region. (2008)
 g-term drought. These conditions exacerbated water
 ling Basin, resulting in widespread crop failures. (2008–
 r to hit Myanmar. It killed more than 70 000 people. (2008)
 ember in northern and central Argentina had record-
 eas. (2009)
 as heatwaves, severe storms, flooding and droughts.

28. Record heatwaves across Australia during January/February, August and November. Disastrous associated bushfires caused more than 170 fatalities. The highest temperature ever recorded so far south in the world was observed in Victoria with 48.8°C. (2009)
29. Extreme cold waves and record snowfalls were observed during winter 2009/2010 in Europe, and large parts of the United States. (2010)
30. Extreme heat and drought in July and August led to disastrous bushfires in the western part of the Russian Federation. (2010)
31. Pakistan experienced the worst floods in its history. More than 1 700 deaths were reported and more than 20 million people were affected. (2010)
32. Heavy rainfall in China contributed to floods and landslides, including a devastating mud-rockslide that killed more than 1 500 people in north-west China. (2010)
33. Extreme precipitation events occurred in West Africa, with the worst flooding in 50 years in Benin. (2010)
34. Flooding affected central and eastern Europe several times during the decade. Poland was most affected in 2001, while Germany, Romania, Austria, Czech Republic and Slovakia were affected in 2002, with thousands of people evacuated. More recently, in 2008, Germany was hit by a large number of thunderstorms with hail and tornadoes. In 2009, some countries suffered from floods similar to those observed in 2002. In 2010, flooding in the Danube river basin caused severe damage. (2001–2010)
35. Australia faced its worst flooding in about 50 years. Floods submerged or disrupted life across an area the size of France and Germany combined. 2010 was the third wettest year over Australia as a whole and the wettest for the state of Queensland. (2010)

A full-page background image showing a massive glacier wall meeting the ocean. The glacier is a bright, jagged white and blue wall stretching across the horizon. The water in the foreground is a deep, textured blue. The sky is filled with heavy, dark grey clouds, with some lighter patches where the sun might be breaking through. The overall mood is dramatic and powerful.

**THE LATEST IPCC REPORT PROJECTS THAT SNOW
COVER WILL CONTRACT AND SEA-ICE EXTENT WILL
DECREASE**

HINDSIGHT ON FORESIGHT: ARE THE OBSERVED FACTS CONSISTENT WITH SCIENTIFIC ASSESSMENTS OF CLIMATE?

The scale of increase in weather extremes is becoming more and more visible. Modern climate science alerted us to this possibility already in 1990.

Projections: 1990

The *IPCC First Assessment Report 1990* of the Intergovernmental Panel on Climate Change noted that high temperature episodes would most likely become more frequent in the future, and cold episodes would be less frequent. This message was reinforced by all subsequent assessment reports.

Projections: 2001

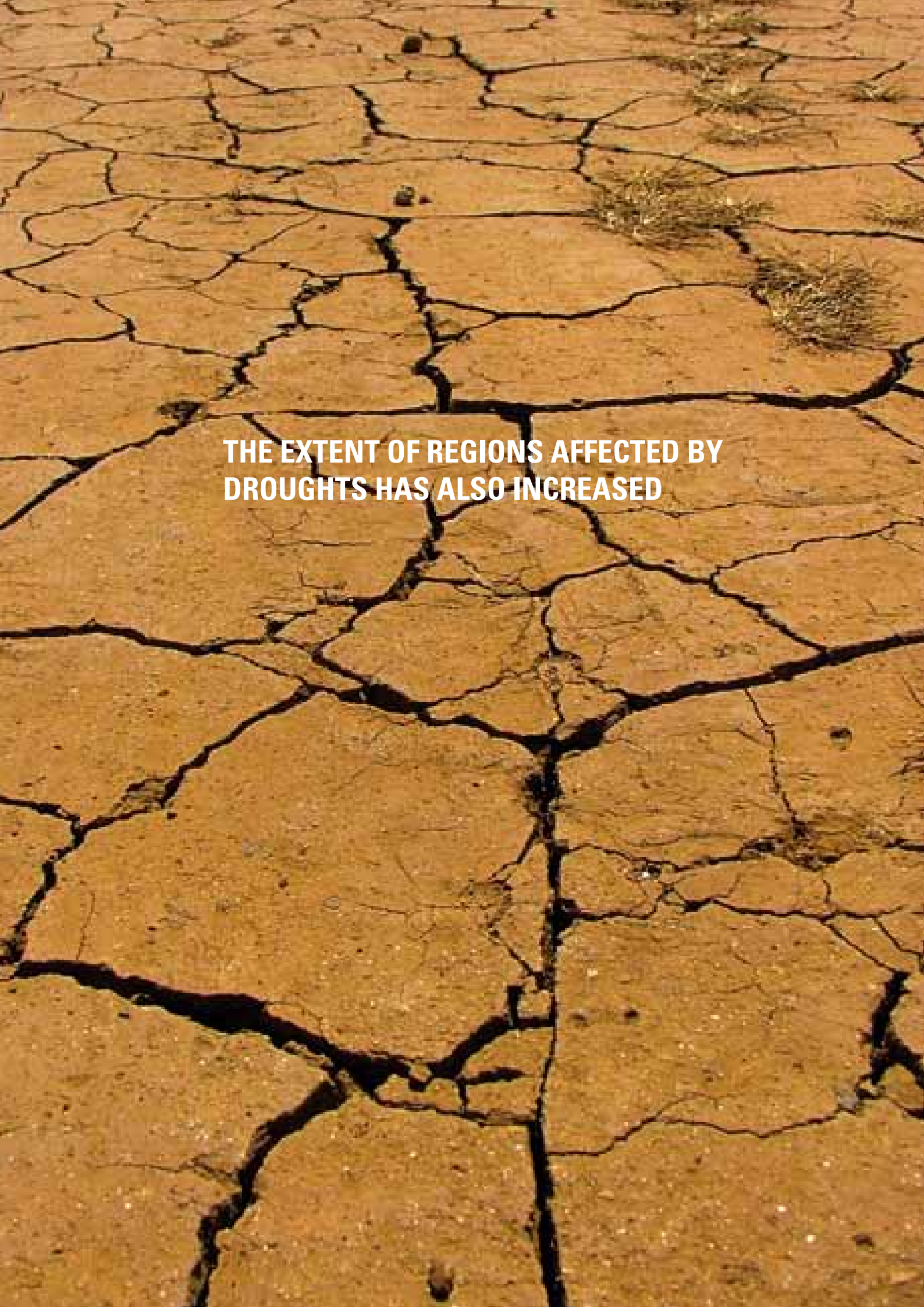
According to the *IPCC Third Assessment Report: Climate Change 2001*, it was “very likely” (90-99% probability) that there would be:

- Higher maximum temperatures, and more hot days over nearly all land areas;
- Higher minimum temperatures, and fewer cold days and frost days over nearly all land areas;
- More intense precipitation events over many areas.

It projected it was “likely” (67-90%) that there would be:

- Increased summer drying over most mid-latitude continental interiors and associated risk of drought;
- Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities over some areas;
- Intensified droughts and floods associated with El Niño events in many different regions;
- Increased Asian summer monsoon precipitation variability.





**THE EXTENT OF REGIONS AFFECTED BY
DROUGHTS HAS ALSO INCREASED**

Projections: 2007

The *IPCC Fourth Assessment Report: Climate Change 2007* projections included:

- Contraction of snow cover area, increases in thaw depth over most permafrost regions, and decrease in sea-ice extent; in some projections, virtual disappearance of Arctic late-summer sea ice in the 21st century;
- A “very likely” increase in frequency of heat extremes, heatwaves and heavy precipitation;
- “Likely” increase in tropical cyclone intensity;
- “Very likely” precipitation increases in high latitudes and likely decreases in most sub-tropical land regions;
- Continued retreat in Northern Hemisphere snow cover, sea-ice extent and glaciers, as well as the Greenland ice sheet.

The *IPCC Fourth Assessment Report* addressed whether there has been a change in extreme events like heatwaves, droughts, floods and hurricanes:

“Since 1950, the number of heatwaves has increased and widespread increases have occurred in the numbers of warm nights. The extent of regions affected by droughts has also increased as precipitation over land has marginally decreased while evaporation has increased due to warmer conditions. Generally, numbers of heavy daily precipitation events that lead to flooding have increased, but not everywhere. Tropical storm and hurricane frequencies vary considerably from year to year, but evidence suggests substantial increases in intensity and duration since the 1970s. In the mid-latitudes, variations in tracks and intensity of storms reflect variations in major features of the atmospheric circulation, such as the North Atlantic Oscillation.”



An aerial photograph showing a massive glacier system with a large iceberg calving into the ocean. The foreground is filled with smaller icebergs and chunks of ice floating in the water. The glacier itself is a mix of white and blue, with visible cracks and layers. The ocean is a deep blue, and the sky is a pale, hazy blue.

**THE MAGNITUDES, FREQUENCY AND DURATION OF
EXTREME EVENTS ARE LIKELY TO BE ALTERED AS
THE EARTH'S ATMOSPHERE WARMS**

CAN WE ATTRIBUTE THE EXTREME EVENTS TO CLIMATE CHANGE?

The years, 2010, 2005 and 1998 ranked as the warmest on record. The decade 2001–2010 was also the warmest ever recorded. The decade was marked by numerous weather and climate extremes, unique in strength and impact. While it is impossible to say that an individual weather or climate event was “caused” by climate change, one should anticipate that the magnitudes, frequency and duration of extreme events are likely to be altered as the Earth’s atmosphere warms due to the increased concentrations of greenhouse gases.

From 2001 to 2010, global temperatures averaged 0.46°C above the 1961–1990 average. Recent warming has been especially strong in Africa, parts of Asia and parts of the Arctic. The Saharan/Arabian, East African, Central Asian and Greenland/Arctic Canada subregions have all had 2001–2010 temperatures 1.2°C to 1.4°C above the long-term average, and 0.7°C to 0.9°C warmer than any previous decade. Overall changes include:

Each decade is warmer.

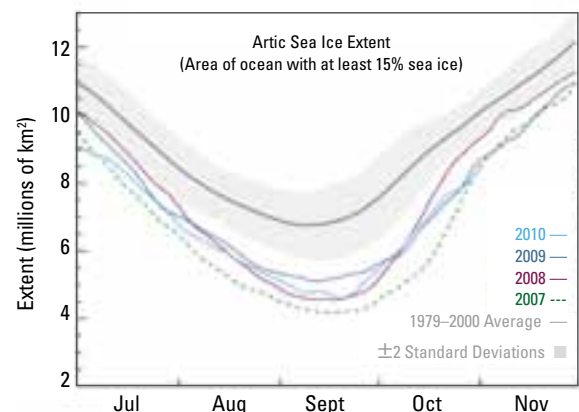
The 2000s decade was warmer than the 1990s, which was warmer than the 1980s and earlier decades.

Ice is melting fast.

At the end of the 2010 melt season (19 September) the sea-ice extent was the third smallest on the satellite data record, after 2007 and 2009. Arctic sea-ice cover in December 2010 was the lowest on record. With an average monthly extent of 12 million km^2 , in December 2010 it was 1.35 million km^2 below the 1979–2000 monthly average (data of U.S. National Snow and Ice Data Center).

Sea level is the highest in 3 000 years.

Global mean sea level is rising more rapidly than at any other time in the past 3 000 years. It has been rising at an average rate of approximately 3.4 millimetres per year from 1993 to 2008. This is almost twice the average rate for the twentieth century.



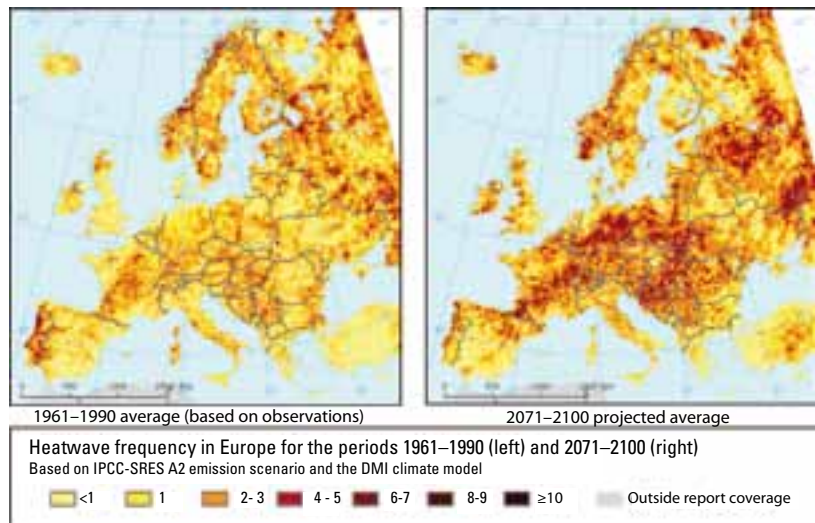
*The years 2007, 2009 and 2010 mark the smallest Arctic sea-ice extent at the end of the melt season.
Source: National Snow and Ice Data Center, USA*



Researching the links

Changes in tropical cyclone intensity, drought severity and frequency, extreme precipitation and temperature anomalies are a focus of current climate research.

For example, there is scientific evidence that supports the link between climate change and frequency of heatwaves. The summer heatwave in Europe in 2003 was the hottest since at least 1540. It is very likely that human influence on climate has at least doubled the current risk of a heatwave such as the one that occurred in 2003, compared to pre-industrial times. Society will face considerable challenges in coping with heatwaves of similar or even greater magnitude to 2003 that are projected to become more common in the future.



Week-long heatwaves are projected to be more frequent in the future.
Source: European Environment Agency

In another example, observation of monsoons in India between 1901 and 2004 showed that they have become more frequent and intense over the last few decades. Another recent study links observed intensification of extreme precipitation over a significant part of the Northern Hemisphere land areas to increases in greenhouse gases.

Scientific understanding of the links between climate change and alterations in the frequency, intensity, and duration of extreme events will be assessed in an IPCC Special Report planned for late 2011.



LOSSES DUE TO EXTREME EVENTS: WHAT WE SHOULD DO

Losses are the result of occurrence of dangerous events and our vulnerability to them. With the current concentrations of greenhouse gases in the atmosphere, climate change is inevitable. This will likely result in a further increase of meteorological extremes.

Reduce the pace of warming

Even by completely “switching off” all emissions now, we will not be able to stop the warming altogether because the Earth atmosphere in its present state is “committed” to some level of warming. However, by reducing greenhouse gases emissions we can reduce the pace of warming and the resulting increase in climate extremes.

Reduce our vulnerability to extreme events

Reducing vulnerability to meteorological extremes should be an essential part of the complex adaptation to climate change. WMO, with its partners, is developing a Global Framework for Climate Services, decided upon in 2009 by World Climate Conference-3, to provide information and services for adapting to climate change. Climate research, led by WMO and its sister research programmes, is developing methods for quantitative estimation of risk of future extreme events and their prediction.

Strengthen research, observation and monitoring

Nations need to strengthen research, observing and monitoring capabilities. This includes sustaining quality with higher density observing networks. There is also the need to develop new methodologies and capabilities for climate system monitoring and climate early warnings. Capacity enhancement for developing and least developed countries should be undertaken as matter of urgency.

WMO is working with Members and partners to strengthen the Global Climate Observing System and the World Climate Research Programme to develop an improved information system for dissemination and access to climate information and products resulting from research and predictions. Collaboration of WMO Members and partners, as well as donors and funding agencies, is necessary to accelerate the operational implementation of these systems at global, regional and national levels.

More on monitoring, forecasts and warnings

WMO Annual Statements on the Status of the Global Climate

http://www.wmo.int/pages/prog/wcp/wcdmp/statement/wmostatement_en.html

World Weather Information Service
<http://worldweather.wmo.int/>

Severe Weather Information Centre
<http://severe.worldweather.wmo.int/>

Meteoalarm – Europe
<http://www.meteoalarm.eu/>

Safety at Sea
<http://weather.gmdss.org/>

WMO El Niño/La Niña Update
http://www.wmo.int/pages/prog/wcp/wcasp/enso_update_latest.html

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