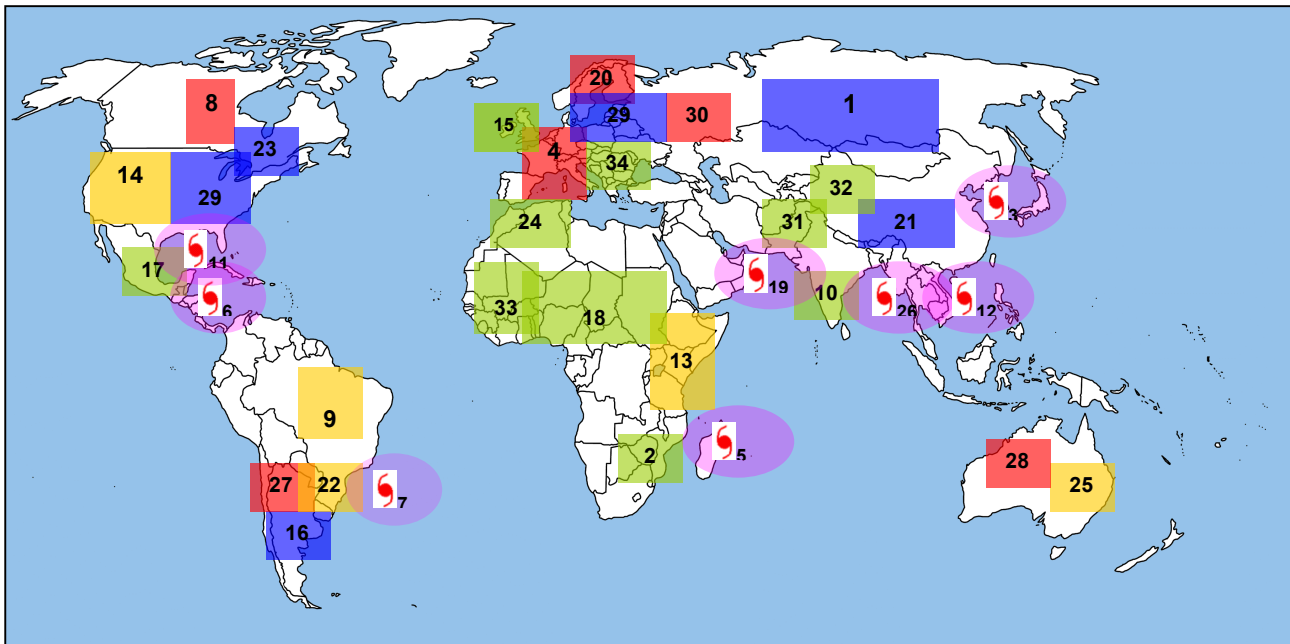


## A SNAPSHOT OF SOME EXTREME EVENTS (\*) OVER THE PAST DECADE



Heat waves / Extreme high temperatures

Cold waves / Extreme low temperatures / Snow storms

Intense storms / Flooding / Heavy rainfall

Severe or prolonged droughts

Tropical cyclones, hurricanes and typhoons

1. Extreme cold winter in Siberia and Mongolia. Minimum temperatures dropped to near  $-60^{\circ}\text{C}$  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-h 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  $40^{\circ}\text{C}$ , and tens of thousands of related deaths. **(2003)**
5. Tropical cyclone Gafilo hit Madagascar with winds up to 260 km/h, causing hundreds of deaths. **(2004)**
6. Hurricane Ivan hit the Caribbean causing flooding, massive destruction and deaths. **(2004)**
7. For the first time on 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 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 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 large parts of southern South America. **(2007)**
17. Massive flooding in Mexico in early November was considered the worst weather-related disaster in the nation's history. **(2007)**
18. Summer heavy rainfall caused flooding and flash floods in several African countries. Thousands of homes were destroyed and more than 1.5 million people were affected. **(2007)**
19. Tropical cyclone Gonu formed in the north Indian Ocean making landfall in Oman and then reaching Iran. It was reported as the strongest cyclone on record in the Arabian Sea. **(2007)**
20. Remarkably mild winter over most parts of Scandinavia. With monthly anomalies exceeding +7°C, large parts of Norway, Sweden and Finland had the warmest winter ever recorded since the beginning of measurements. **(2008)**
21. Extreme cold temperatures combined with the worst snowstorm in 5 decades were observed across China during January. The extreme cold event extended as far west as Turkey. **(2008)**
22. Severe prolonged drought hit Argentina, Uruguay, Paraguay and southern Brazil causing severe damage to agriculture, livestock and water resources. For large areas it was one of the driest years on record. **(2008)**
23. Several all time winter snowfall records were set across Canada. **(2008)**
24. During September-November period heavy and extended rainfall affected Algeria and Morocco, causing severe infrastructure damage. These were the worst floods in a century for Algeria. A similar meteorological situation was repeated one year later across the same region. **(2008)**
25. In southern Australia dry conditions reinforced long term drought. These conditions exacerbated severe water shortages in the agriculturally important Murray-Darling Basin, resulting in widespread crop failures. **(2008-2009)**
26. Tropical cyclone Nargis was the worst natural disaster to hit Myanmar. It killed more than 70 000 people. **(2008)**
27. Exceptional heat wave in late October/early November in northern and central Argentina, with record breaking temperatures of more than 40°C in large areas. **(2009)**
28. Record heat waves across Australia during January/February, August and November. Disastrous bushfires associated caused more than 170 fatalities. Highest temperature ever recorded so far south anywhere 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 western Russia. **(2010)**
31. In summer 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 which killed more than 1,500 people in Zhoqu County, northwest China **(2010)**
33. Extreme precipitation events 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 in 2002, with thousands of people evacuated. More recently, in 2008, Germany was hit by a large number of thunderstorms with hail and tornadoes and some countries in 2009 suffered from similar floods like those observed in 2002. In 2010 flooding in Danube river basin caused severe damage. **(2001-2010)**

*\* In the absence of a standard definition of an extreme event, this map includes single and/or a succession of weather phenomena leading to abnormal meteorological and/or climate conditions with high impacts such as heat waves, severe storms, flooding, droughts, etc.*

# Weather Extremes in a Changing Climate: Hindsight on Foresight

The observed climate anomalies and the devastating weather events recorded in 2010 have further triggered the interest of the general public, governments, and media in knowing if we are likely to see more frequent and more intensive extreme (rare but high impact) weather events in the years to come. This short note gives food for thought to address this question based on the activities of the WMO and its co-sponsored programmes, which include observing and monitoring of, as well as research on, weather, climate and water, and their extremes.

## Extreme weather events in the recent years

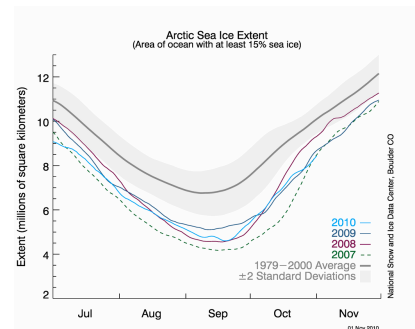
WMO publishes annual reports on the Status of the Global Climate, summarizing significant events observed during the past year, including El Niño/La Niña episodes which have an important impact on temperatures and precipitation, and comparing them with historical records. A brief extract from these reports and a summary for 2010 are given below.

### Overall changes

The 10 warmest years on record have all occurred since 1998. The 2000s decade was warmer than the 1990s which was warmer than the 1980s and earlier decades. The first ten months of 2010 tied the same period in 1998 for the warmest combined land and ocean surface temperature on record worldwide, according to the U.S. National Oceanic and Atmospheric Administration and the UK Met Office's Hadley Centre .

On 19 September 2010 at the end of the melt season the sea-ice extent was the third smallest on the satellite data record, after 2007 and 2009 (data of U.S. National Snow and Ice Data Center).

Global mean sea level is higher now and is rising more rapidly than at any other time in the past 3 000 years at the pace of approximately 3.4 millimetres per year from 1993 to 2008, according to data published by the WMO co-sponsored World Climate Research Programme. This is almost twice the average rate for the twentieth century.



### Examples of weather extremes in recent years

**1998:** The Earth's global temperature was the highest since the start of modern instrumental records, and many countries witnessed severe heat waves and droughts. The global mean surface temperature was estimated at 0.52 °C above the 1961-1990 long-term average. An episode of extremely high ocean temperatures in the Indian Ocean due to a strong El Niño event in 1997 and the first half of 1998 caused unprecedented bleaching of coral reefs – the “rainforests of the ocean”. In the United States of America, spring and summer heat and drought caused massive wildfire outbreaks in Florida. April-June was the driest period in 104 years of record in the USA state of Florida, Texas, Louisiana, and New Mexico.

**2000:** Severe flooding from excessive summer monsoon rainfall in parts of southern India, and in Bangladesh, Cambodia, Thailand, the Lao People's Democratic Republic and Viet Nam resulted in loss of life and extensive property damage. More than 10 million people were affected in India alone with over 650 deaths. Successive tropical cyclones that struck Madagascar, Mozambique and southern Africa early in the year caused severe flooding which led to hundreds of casualties.

The third consecutive year of below-normal rainfall in the greater Horn of Africa aggravated existing drought conditions over much of the area, resulting in severe food shortages. Tens of millions of people were affected; especially hard hit were Ethiopia, and parts of Djibouti, Eritrea, Kenya, Somalia and the United Republic of Tanzania.

**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 Russia, 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 18<sup>th</sup> 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. At 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 additional deaths were attributed to the heat waves according to WHO and other organizations. In the European Alps, the average thickness loss of glaciers reached about three metres water equivalent, nearly twice as much as during the previous record year of 1998. The heat waves resulted from a zone of 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. Record number of ten tropical cyclones (previous record six) made landfall in Japan, including Typhoon Tokage which was the deadliest to hit Japan since 1979. In March, the first documented 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 north-east China experienced the worst drought conditions since 1951, and southern China received the lowest autumn rainfall since 1951.

**2005:** 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. 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 of America, Hurricane Katrina was the deadliest hurricane to hit the country since 1928, killing over 1300 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, 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 1961-90 average.

**2006:** Heavy rains ended prolonged drought in Greater Horn of Africa, leading to 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 June-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.

**2008:** China witnessed the worst severe winter weather in five decades in January; 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 large parts of Norway, Sweden and Finland, it was the warmest winter ever recorded since the beginning of measurements. Tropical Cyclone Nargis (May) with maximum winds of 215 km/h was the most devastating cyclone to strike Asia since 1991, causing the worst natural disaster ever in Myanmar. 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.

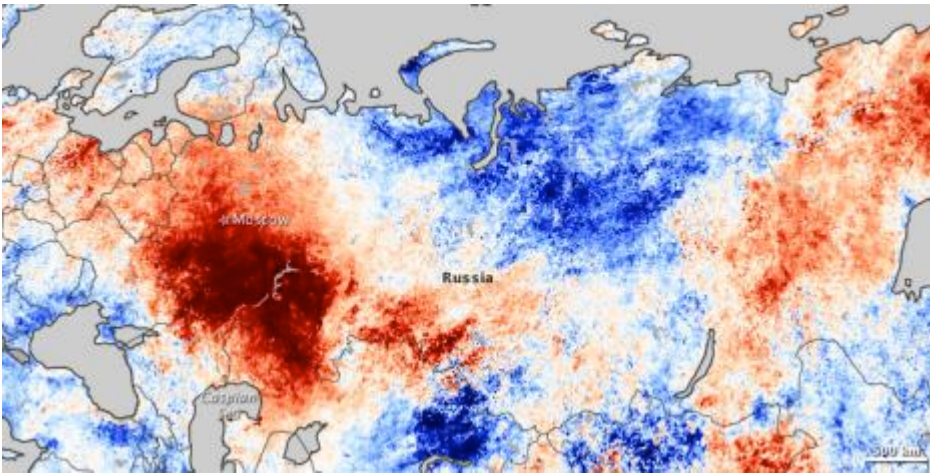
**2009:** Australia was marked by exceptional heatwaves, which affected the south-eastern part of the country in January/February. This was associated with disastrous bushfires that caused more than 170 fatalities. Victoria recorded its highest temperature with 48.8°C at Hopetoun, the highest temperature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

**2010:** The 2009/2010 winter was characterized by extremely cold temperatures over large parts of the northern hemisphere, including parts of Europe, Asia and 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 boreal summer of 2010 witnessed a sequence of devastating extreme events associated with unprecedented impacts in many cases. 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 districts out of a total 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 (compared to the previous record in July 1938 which 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 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.



Satellite image of the heat wave in Russia (NASA image August 9, 2010 )

The devastating Russian heat wave and Pakistan floods 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 still continuing, 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 in Northwest China was hit by the most devastating flood and mud-rock flow in the history of the People’s Republic of China, killing more than 1,500 people.

Greenland will record its warmest decade (2001-2010) since modern measurements. Most stations in West Greenland especially in the south western part will very likely record its warmest ever year in 2010. In August, ice measuring more than 200 sq. km 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 and because of its size more typically resembled icebergs in the Antarctic.

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.

## **Are the observed facts consistent with scientific assessments of climate?**

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

According to *the First IPCC Assessment Report in 1990*, episodes of high temperature would most likely become more frequent in the future and cold episodes less frequent. This message was reinforced by all subsequent assessment reports.

According to *the Third IPCC Assessment Report in 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 predicted 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 Fourth Assessment Report 2007* projections included:

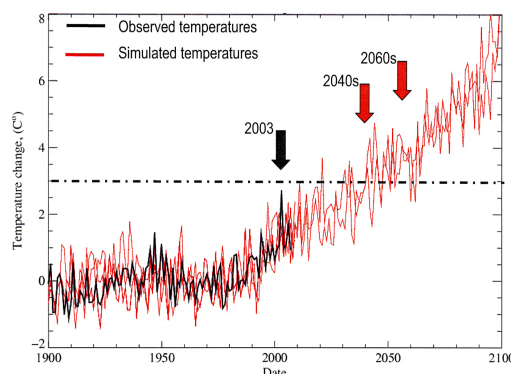
- Contraction of snow cover area, increases in thaw depth over most permafrost regions, and decrease in sea-ice extent; in some projections, virtual disappearance of Arctic late-summer sea ice by the latter part of the 21st century
- A “very likely” increase in frequency of heat extremes, heat waves 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 Fourth Assessment Report* addressed whether there has been a change in extreme events like heat waves, droughts, floods and hurricanes. “Since 1950, the number of heat waves 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.”

## Can we attribute the extreme events to climate change?

The probability of occurrence of meteorological extremes varies in time and space. One of the most important challenges for climate scientists is to estimate their future probabilities and, where possible, predict significant long-lasting anomalies of weather.

While it is impossible to say that this or that weather event was “caused” by climate change, one should anticipate that the magnitude, frequency and duration of extreme events will likely be altered as a result of the Earth’s atmosphere warming due to the increased concentrations of greenhouse gases. For example there is scientific evidence that supports the link between climate change and frequency of occurrence of, heat waves. The summer heat wave 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 risk of a heat wave such as one occurred in 2003. Society will face considerable challenges in trying to cope with heat waves of similar or even greater magnitude to 2003 that are projected to become more common in the latter decades of the 21st century.



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 to be released in the 4th quarter of 2011.

## Losses due to extreme events: what we should do

Losses are the result of occurrence of dangerous events and vulnerability to them. With the current concentrations of greenhouse gases in the atmosphere, the Earth is committed to continuing warming and this will likely result in further increase of occurrence of meteorological extremes. Even by completely “switching off” all the 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 the emissions of greenhouse gases we will be able to reduce the pace of the warming and the resulting increase in climate extremes.

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 the WMO-cosponsored World Climate Research Programme and its sister research programmes, is developing methods for quantitative estimating of risk of future extreme events and their prediction.

Nations need to strengthen research, observing and monitoring capabilities including sustained high quality with higher density observing networks. Members 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 to develop an improved information system for dissemination and access to climate information and product 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.

December 2010