# STATE OF THE CLIMATE IN 2010

J. Blunden, D. S. Arndt, and M. O. Baringer, Eds.

Associate Eds. K. M. Willett, A. J. Dolman, B. D. Hall, P. W. Thorne, J. M. Levy, H. J. Diamond, J. Richter-Menge, M. Jeffries, R. L. Fogt, L. A. Vincent, and J. M. Renwick

**Special Supplement to the**
***Bulletin of the American Meteorological Society***
**Vol. 92, No. 6, June 2011**

# 7. REGIONAL CLIMATES

*a. Overview*—L. A. Vincent and J. Renwick, Eds.

This chapter provides a regional perspective of the global climate in 2010, with a focus on unusual or extreme events. Analyses are provided for continents, broad geographic regions, and nations. Information for the year is placed into a historical context using anomalies (relative to 1961–90, unless otherwise noted), percentage anomalies, and rankings. Authors for most regions are local scientists and data is made available by their affiliated agency. While this chapter covers the climate of 2010, information from the previous year may be included in order to accurately cover relevant climate seasons (e.g., austral summer and boreal winter seasons typically include data from December 2009).

On average, temperatures were exceptionally warm in Canada and Greenland, western Russia, parts of the Middle East, much of south Asia, and over much of Africa. A few parts of the world were significantly colder than average, such as Western Europe and parts of North America during the winter months. Droughts affected large parts of South America, especially in Amazonia, Bolivia, Chile, and Argentina. Very wet conditions were recorded in Mexico, northern and western Africa, the Iberian Peninsula, Eastern Europe, Pakistan and the Himalayan region, and in central and eastern Australia.

*b. North America*

1) Canada—R. Whitewood and D. Phillips

The year 2010 was the warmest year since nationwide records began in 1948. The temperature was above normal for most of the country and during all seasons. The country also experienced a slightly wetter than normal year in 2010.

*(i) Temperature*

The national average temperature for 2010 was 3.1°C above the 1961–90 normal, which was the warmest year since nationwide records began in 1948 (Fig. 7.1). The previous record year was 2006 (+2.5°C) and 1972 (-1.9°C) remains the coolest. The annual average temperature has been above normal since 1997. Much of Canada's above-normal temperatures during 2010 were experienced in the north, where temperatures were more than 3.5°C above normal (Fig. 7.2a). Most of Nunavut and northern Quebec were at least 4°C above normal and only a small area over southern Alberta and Saskatchewan was near normal. The national annual average temperature shows a linear increase of 1.8°C over the 63-year period (Fig. 7.1).

Seasonally, the Canadian winter 2009/10 was the warmest on record. The national average temperature was 3.9°C above normal. The mean temperature departure was above normal for most of the country, with some areas of the Arctic and northern Quebec more than 6°C above normal. A small area over the southern Prairies had a cooler-than-normal winter; in particular, in southern Saskatchewan, where temperatures were more than 1°C below normal.

Spring 2010 was also the warmest spring on record and had the greatest seasonal anomaly. The national average temperature for this period was 4.1°C above normal. The mean temperature departure was above normal across the country with no regions reporting below-normal temperatures; some areas of the Arctic and northern Ontario were more than 6°C above normal.

The national average temperature for summer 2010 was 1.3°C above normal, which makes this the third warmest summer on record. The mean temperature departure was above normal over most of the country, with some areas of Nunavut Territory, northern Quebec, and central Manitoba more than 2°C above normal. Only a small area over the southern Prairies was slightly cooler than normal.

Autumn 2010 was the second warmest autumn on record. The national average temperature was 2.4°C above normal. The mean temperature departure was above normal for most of the country, with most of Nunavut, northern Quebec and central Manitoba at least 4°C above normal. Southern British Columbia, Alberta, and Saskatchewan were near normal.

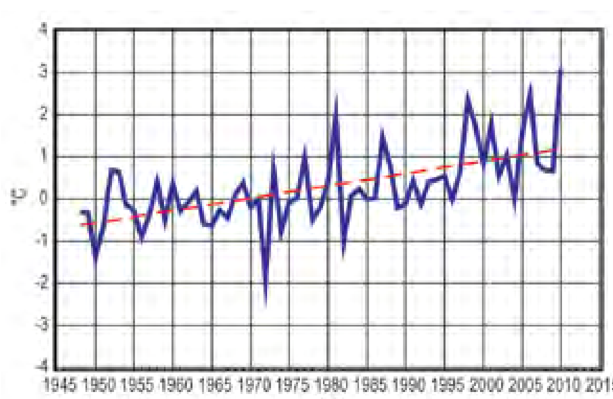


**Fig. 7.1. Annual mean temperature anomalies for Canada (based on 1961–90) for the period 1948–2010. (Source: Environment Canada.)**

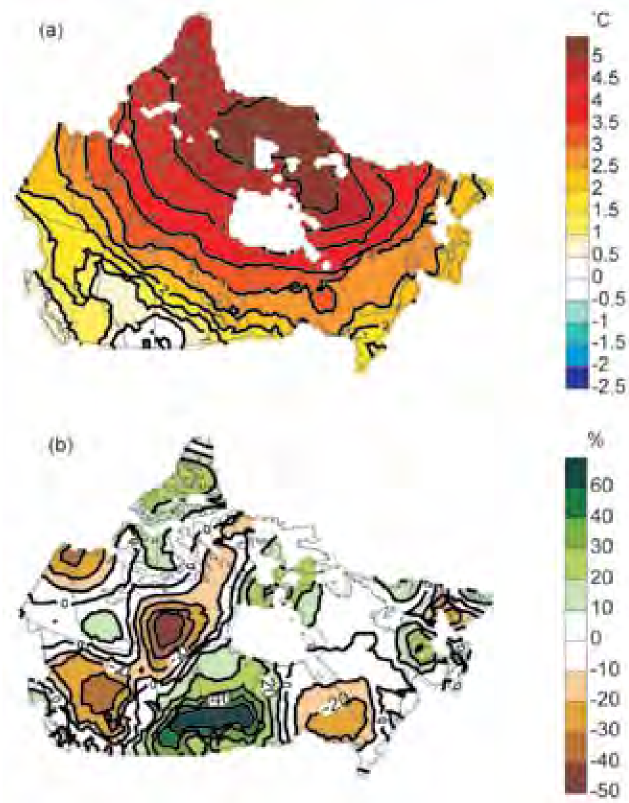


**FIG. 7.2. (a) 2010 annual mean temperature anomalies (°C) for Canada (based on 1961–90 mean) and (b) 2010 annual precipitation anomalies (% of 1961–90 mean). (Source: Environment Canada.)**

*(ii) Precipitation*

Overall, Canada experienced a slightly wetter-than-normal year in 2010 (2% above normal), which ranked as the 28th wettest in the 63-year period of record. Saskatchewan and Manitoba were more than 20% wetter than normal while central British Columbia, northern Alberta, Northwest Territories, and northern Ontario were at least 20% drier than normal (Fig. 7.2b). Since the 1970s, precipitation across Canada has tended to be higher than the 1961–90 average. The wettest year on record occurred in 2005 (15% above normal) and the driest year was 1956 (12% below normal).

Seasonally, winter set a record as the driest (22% below normal); the previous driest winter was observed in 1956/57 (20% below normal). The drier-than-normal conditions were widespread, with most areas of the country having at least 20% less precipitation than normal. Some areas, including parts of British Columbia, Alberta, Saskatchewan, and Ontario had 60% less precipitation than normal. Only two areas—central Nunavut and western Labrador—had more precipitation than normal.

Spring 2010 was 1% below normal (31st driest). The Canadian Prairies were wetter than normal, as well as areas of southern British Columbia, the Arctic islands, Newfoundland, and Labrador. Ontario through the Maritimes and areas of northern British Columbia, Yukon, southern Northwest Territories, and Nunavut were at least 20% drier than normal this spring.

Summer 2010 was 5% above normal (15th wettest). The Prairies, southern Ontario, northern Nunavut and western Northwest Territories all experienced at least 40% more precipitation than average. Almost all of British Columbia, along with southern Nunavut and Northwest Territories, experienced conditions that were at least 40% drier than normal.

Canada also experienced a wetter-than-normal autumn, at 5% above normal (22nd wettest). The Prairies, southern Quebec, the Maritimes, and areas of southern Nunavut and southern Yukon Territories all experienced at least 40% more precipitation than average this autumn. Northern Alberta, northern Yukon, northern and southern Northwest Territories, and northern Nunavut experienced conditions that were at least 40% drier than normal.

*(iii) Notable events*

In February, Canada was on the world stage hosting the XXI Olympic Winter Games in Vancouver-Whistler, British Columbia. The organizers could not anticipate that the Olympic city would experience its mildest winter ever and one that was practically snow-free. The winter started off well enough, with November setting a record of over five meters of snow in the alpine area of Whistler-Blackcomb and December colder than normal by about 1.5°C. However, the New Year brought a soaking Pineapple Express, making January in Vancouver feel more like April. The city did not receive any snow after 14 December, where it normally averages 35 cm. In the 50 days leading up to the opening ceremonies, Vancouver received no snow and 247.2 mm of rain. Up to 300 workers toiled around the clock at the snowboarding venue, moving 9000 cubic meters of snow from as far as 250 km away. By the beginning of the first full week of the Winter Olympics, the stubborn Pacific low moved south and was replaced by a blocking high pressure system with its bright, clear skies and mild, dry weather for seven straight days. In the final days, however, the blocking pattern broke and cloudy, showery weather took hold once again.

On 21 September, Hurricane Igor was still a hurricane as it tracked just offshore of Newfoundland but became a post-tropical storm as it came ashore. Hurricane-force winds ripped across eastern Newfoundland with a savagery that forced 22 flooded and wind-battered towns to declare states of emergency. Over 150 communities became isolated when swollen rivers washed away the only roads into town and all connecting bridges. A peak wind speed of 93 kts (48 m $s^{-1}$) was recorded at Cape Pine in southeastern Newfoundland and Labrador. In addition to taking out power for 70 000 hydro customers, water flowed everywhere, overwhelming culverts, filling basements, and eroding road beds. The Insurance Bureau of Canada reported that insurable claims related to Igor amounted to $65 million (Canadian dollars)—only a fraction of the total losses—yet was the biggest weather-related insurance claim in Newfoundland and Labrador in recent history.

The Prairies experienced a dramatic switch in weather during the growing season in 2010. At the beginning, Western ranchers said they had never seen such a dry spring. In Camrose, Alberta, a drought was declared before April and, across the Prairies, agricultural producers hoped and prayed for rain. With minimal snow cover and record-low precipitation between January and March, winter 2009/10 gave growers little optimism. However, spring brought above-normal temperatures and in April, it started to rain. Unfortunately, it did not stop, and by mid-May, farmers' drought worries were gone, replaced with worries of flooding, with some farmers unable to get on to their soaked fields. There was twice as much rain and snow as normal during April and May. As the rains persisted into June, farmers grew more concerned. Nearly a quarter of the Prairie grain crop had yet to be sown. With a scarcity of hot days and sunshine, water was not evaporating and crops were not maturing. Fortunately, growers finally got a break on the first day of the fall when warm, dry, and sunny conditions set in and prevailed through October. The perfect weather enabled farmers to make up for lost time. Almost every day over four weeks had maximum temperatures above normal and it was dry. Growers worked night and day and, incredibly, harvested a record 70% of the crop in three weeks. In the end, nearly 40 rural municipalities declared themselves agricultural disaster areas. Statistics Canada reported 15% less wheat harvested than in 2009.

2) United States—C. Fenimore, J. Crouch, and R. R. Heim Jr.

Based on preliminary data, the annual average temperature in 2010 for the contiguous United States was 12.1°C, which is 0.5°C above the long-term or 20th century average (LTA), the 23rd warmest year since records began in 1895 (Fig. 7.3). The Northeast had their third warmest year on record and it was the eighth warmest for the East North Central climate region (Great Lakes area). Only the Southeast experienced an average temperature that was below the LTA.

Above-average precipitation anomalies prevailed throughout much of the country in 2010, resulting in the 35th wettest year on record. Precipitation anomalies were especially high in the northern Great Plains and Upper Mississippi Valley, where the East North Central and the West North Central climate regions had their third and fifth wettest year on record, respectively. Only the South, Southeast, and portions of the Ohio River Valley had precipitation averages that were below normal for the year.

*(i) Temperature*

Anomalous warmth returned in 2010, after two years of experiencing near-normal temperatures in the contiguous United States. Since 1895, the contiguous U.S. has observed a temperature increase of about 0.07°C per decade. Extreme fluctuations in temperature during 2010 can be partially attributed to three large-scale atmospheric circulation patterns: the historically strong negative Arctic Oscillation (winter), the persistent Bermuda High (spring–summer), and La Niña (summer–fall). The 2010 temperature pattern on a statewide level consisted of warm anomalies throughout much of the country, especially

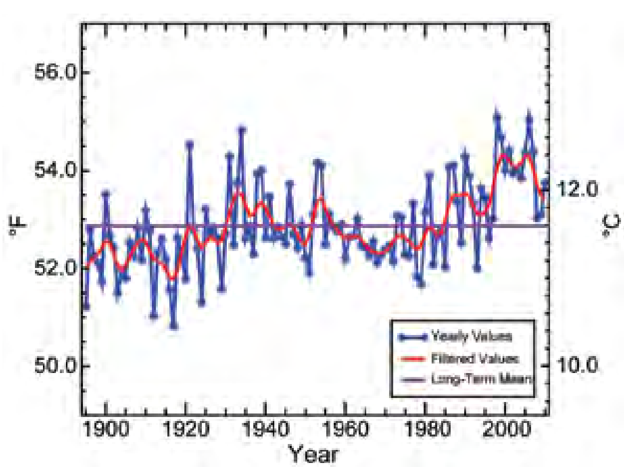


**Fig. 7.3. Annual mean temperature for the contiguous United States for the period 1895–2010. The filter is a weighted average that is used to smooth the year-to-year changes in the data values which may help identify the presence/absence of trends throughout the data record. (Source: NOAA/NCDC.)**

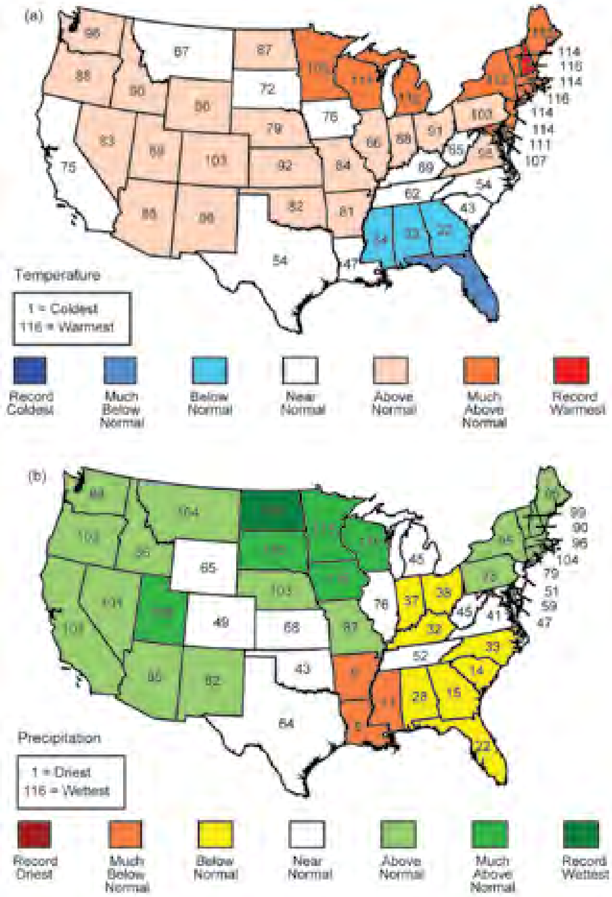


**Fig. 7.4. Statewide ranks of annual 2010 (a) temperature and (b) precipitation. A rank of 116 represents the warmest/wettest year since 1895. Much-above-normal temperature/precipitation is defined as occurring in the top 10% of recorded years. Above-normal temperature/precipitation is defined as occurring in the warmest/wettest third of recorded years. Much-below-normal temperature/precipitation is likewise the bottom 10% of coolest/driest years since 1895, and below normal is defined as the coolest/driest third of the distribution. (Source: NOAA/NCDC.)**

in the Northeast where the warmest year on record for New Hampshire and Rhode Island (Fig. 7.4a) was attributed to the persistent warmth. Also among their top ten warmest were Michigan, Wisconsin, and Minnesota. The only four states that were cooler than normal were Florida, Georgia, Alabama, and Mississippi.

Cool anomalies were present across much of the contiguous U.S. during the winter (December 2009–February 2010) season. Consistent with what is typically seen during negative Arctic Oscillation events, the coldest temperature anomalies for the period occurred in the Southeast and Southern Plains, where the majority of states experienced an average temperature that was among their coldest 10% on record. In the extreme Northeast, a blocking pattern that typically occurs during negative Arctic Oscillation events contributed to Maine's third warmest winter, nearly 3.3°C above the LTA. Nationally, the average winter temperature was 1.0°C below the LTA, resulting in the 15th coolest on record and coolest winter period since 1964.

Extreme warmth continued in much of the Northeast during the spring, contributing to the region's warmest March–May on record. The regional temperature average was more than 3.0°C above the LTA. Eight northeastern states experienced their warmest spring on record, as did Michigan. Cool anomalies were present in several western states and in Florida. Nationally, it was the 19th warmest spring on record.

Warmer-than-average conditions prevailed throughout much of the contiguous U.S. during the summer. Induced by a combination of a persistently strong Bermuda High that extended abnormally westward and a strengthening La Niña episode, the Southeast had its warmest summer on record. Demonstrative of this irregularity, there were several other climate regions that were abnormally warm: Central (3rd warmest), Northeast (4th warmest), and the South (7th warmest). It was the warmest summer in 116-years of record keeping for every state in the Southeast climate region. A total of 12 states were record warm, while only two (Montana and Oregon) experienced an average temperature that was below the LTA. Overall, it was the fourth warmest summer on record for the contiguous U.S., with an average temperature of 1.0°C above the LTA.

Abnormal warmth continued into the fall season. While spatial temperature averages were variable across climate divisions, nearly every state averaged a temperature that was above the LTA. Rhode Island (6th warmest), Delaware (7th), and New Jersey (11th) each experienced the warmest anomalies, while Florida, Georgia, Michigan, Montana, and Washington were the only states with average temperatures near the LTA.

The average annual temperature for Alaska in 2010 was 0.4°C above the 1971–2000 average. Following a year with below-average temperatures, these above-normal temperatures were a continuation of the upward trend of the last 20 years. Temperatures during winter 2009/10 were 1.7°C above average. Seasonal anomalies in Alaska coincided with the contiguous U.S. during the remainder of the year as spring temperatures were 0.4°C above average, summer was 0.2°C above average, and fall was 1.7°C above average.

*(ii) Precipitation and snowpack*

Average precipitation for the contiguous United States in 2010 was 26 mm above the long-term average of 740 mm. Precipitation across the U.S. during the year was characterized by persistent wetness in the Upper Midwest, resulting in record to near-record averages for the area (Fig. 7.4b). While not as extreme as the aforementioned area, much of the western United States also experienced above-normal precipitation. Elsewhere, precipitation averages in the South and Southeast were below the LTA. Examining precipitation anomalies at the statewide level, it was the wettest year on record for North Dakota and second wettest for Iowa, Minnesota, and Wisconsin. Persistent dryness in the South contributed to the fifth driest year on record for Louisiana and ninth driest for Arkansas. Seasonally, it was the third wettest winter period for the Southeast and the 11th wettest for the Southwest.

It was the 15th wettest winter (December 2009–February 2010) for the U.S. in the 1895–2010 period of record. As a result of the ongoing El Niño episode, a persistent Pacific jet stream extended over the southern half of the contiguous United States. The episode contributed to the third wettest winter in the Southeast. It was the fifth wettest winter for Georgia, North Carolina, and South Dakota and the sixth wettest such period for Alabama, New Jersey, New Mexico, South Carolina, and Virginia.

Spring precipitation varied in 2010, resulting in a national average that was near normal. Based on climate division averages, record dryness occurred in the Upper Peninsula of Michigan and northern Louisiana. At the statewide level, Louisiana had its fifth driest spring on record.

Summer precipitation, when averaged across the contiguous United States, was the ninth wettest on record. The active pattern across the northern tier states peaked in June, resulting in the wettest June on record for the Great Lakes area. Both Michigan and Iowa had their wettest June on record, while Illinois, Indiana, and Wisconsin each had their second wettest. The relentless pattern subsided only slightly in July, when the region experienced its third wettest such period. For the entire summer period, Wisconsin was record wet, and it was second wettest for Iowa, third wettest for Michigan and Nebraska, while Indiana, Minnesota, and South Dakota each had their sixth wettest such period.

Several states experienced a precipitation average that was either in the top or bottom 10% on record during the fall season. Florida had its second driest fall on record while the precipitous pattern continued for the Great Lakes region where Minnesota had its third wettest such period. Elsewhere, Maine and Nevada experienced their fifth and seventh wettest fall on record, respectively.

During winter 2009/10, snowpack levels varied across the mountainous western United States. Mountain snowpack was below normal for the Cascade Mountains and the northern and central Rockies. Some regions of the Oregon Cascades, western Wyoming, the Bitterroot Range, and the Columbian Plateau had snow packs that were less than 50% of normal. While almost all of Alaska had snow packs below normal, the central regions of the state had snow packs less than half their normal levels. Conversely, the Sierra Nevada range of California and the southern Rockies had snow packs that were above normal by the end of the winter season. Additionally, the mountains of Arizona and New Mexico also had snow packs that were more than 180% of normal.

The 2009/10 winter brought unusually snowy conditions to the eastern two-thirds of the United States. An active storm track across the Northern Plains as well as the Southeast and along the Eastern Seaboard brought several large record-breaking snow storms. During December 2009, the U.S. experienced its largest snow cover extent on record. It was the sixth largest January snow cover extent and the third largest February extent. Several locations broke seasonal snowfall records, including Washington, D.C. (186 cm), Baltimore (204 cm), and Philadelphia (200 cm). It was also the snowiest February on record for New York City (94 cm) and Pittsburgh (130 cm).

*(iii) Drought and wildfires*

The drought epicenters during 2010 were the western Great Lakes, much of the Southeast, the Ohio Valley, the mid-Atlantic states, Hawaii, and parts of the West. The year started out with drought in the West, small parts of the Southern Plains, and the Great Lakes. During the spring, drought developed in parts of the South and intensified in the western Great Lakes. Drought conditions contracted in the West and western Great Lakes, but intensified in the Southeast and mid-Atlantic states during the summer. By October, moderate to extreme drought had developed in the South and spread into the Ohio Valley. Drought relief occurred in the Ohio Valley with heavy rains at the end of November. About 75% of Hawaii suffered through a prolonged dry spell for most of the year, but heavy rains brought limited relief in December. In spite of the rains, this year's drought ranked as the worst drought episode of the decade for Hawaii. In the contiguous U.S., low stream, reservoir, and stock pond levels, and depleted soil moisture combined with hot temperatures and high evaporation to ravage agricultural lands as the growing season progressed: in the Mid-Atlantic states by mid-summer, and the South and Ohio Valley by early to mid-fall. Dryness was especially severe in the Lower Mississippi Valley, with parts of Arkansas, Louisiana, and Mississippi having the driest year on record.

The United States had a below-average wildfire season for 2010. Wet conditions across the western regions of the country helped to limit the number of large fires and total acreage burned. During 2010, 71 839 fires burned nearly 1.4 million hectares. This marked the least acreage burned annually nationwide since 1998. Despite the below-average season, the Long Butte Fire in Idaho burned approximately 133 000 hectares during August, about nine percent of all acres burned in the United States during the year. The Fourmile Canyon fire near Boulder, Colorado in September only burned 2500 hectares, but containment costs and damages totaled more than $225 million (U.S. dollars)—the costliest fire in Colorado's history.

*(iv) Tornadoes*

Across the United States, 2010 was an above-average year for tornadoes. As of March 2011, confirmed tornado reports and estimates for 2010 indicated that there were 1280 tornadoes from January to December, which is above the 10-year (2000–09) average and the seventh highest annual count since 1990. The number

## SIDEBAR 7.1: AN ASSESSMENT OF 2010 NORTH AMERICAN TEMPERATURES—M. HOERLING, D. EASTERLING, J. PERLWITZ, J. EISCHEID, P. PEGION, AND D. MURRAY

**A Persistent Pattern of 2010 North American Temperature Anomalies**

Surface air temperatures were very warm across Canada during all seasons of 2010, while the contiguous United States experienced much-below normal temperatures over the South and East in the first and latter portions of 2010. These cold conditions ended record high temperatures in those same U.S. regions during the warm half of the year (Fig. 7.5, left panels). January–March 2010 conditions included greater than +3°C departures over all Canadian provinces from the Pacific to the Atlantic coast; statistics compiled by Environment Canada indicated that winter 2010 was the warmest in Canada since records began in 1948. In sharp contrast, up to -3°C departures occurred over the U.S. Gulf Coast region. Following seasons

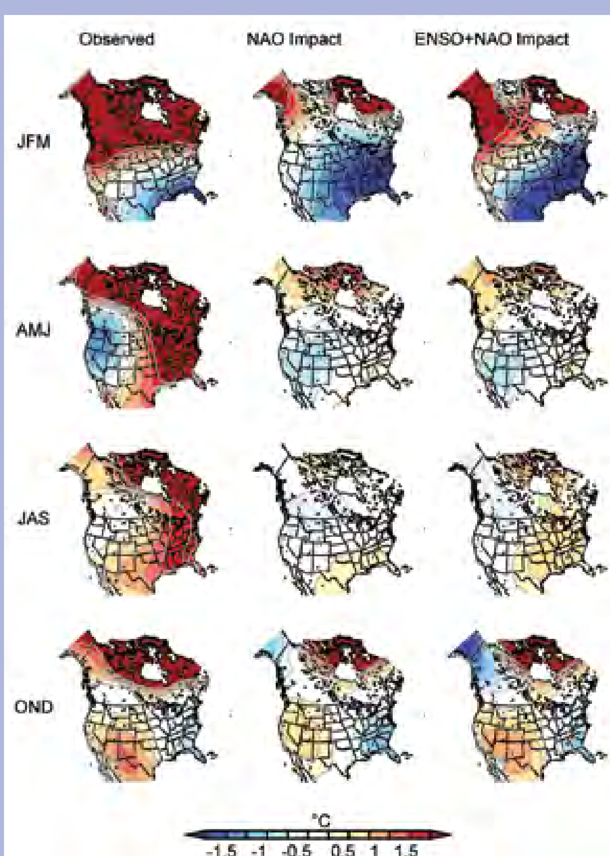


**Fig. 7.5. (Left panels) North American surface air temperature departures (°C) during 2010 for winter (JFM), spring (AMJ), summer (JAS), and fall (OND) based on NASA gridded departures (based on 1961–90); (middle panels) surface temperature signal (°C) attributable to the state of the 2010 North Atlantic Oscillation (NAO); (right panels) surface temperature signal (°C) attributable to the combined effects of the state of NAO and ENSO. The NAO signal is calculated by regressing the monthly surface temperatures upon the Climate Prediction Center's NAO index time series for 1950–2009, and the 2010 anomalies are derived by multiplying the regression pattern by the observed 2010 standardized NAO index for each season. The ENSO signal is calculated by regressing the monthly surface temperatures upon a Nino-3.4 SST index time series for 1950–2009 and then scaling by the observed 2010 index values of Nino-3.4 SSTs. The combined 2010 anomalies are derived by adding the separate NAO and ENSO signals. All data used in regression were detrended. (Source: NOAA/ESRL-PSD1/GISS.)**

of strong-to-violent tornadoes (rated EF3–EF5) reported in 2010 was 43, which was also above average, although no tornadoes were rated EF5. There were 45 tornado fatalities reported during 2010, associated with 21 tornadoes. The most deadly tornado of the year occurred in the state of Mississippi on 24 April, when a long-track EF4 killed 10 people in three counties. The tornado was on the ground for 240 km, the fourth longest tornado track for Mississippi on record.

Texas led the national tornado count with 107 individual tornadoes during 2010. Also remarkable were the 105 confirmed tornadoes that occurred in Minnesota, ranking the state as having the second most tornadoes in the United States during the year. The 105 tornadoes broke the state's previous annual record of 74, which occurred in 2001. Forty-eight of the Minnesota tornadoes occurred on 17 June alone, as part of the largest tornado outbreak during 2010 for the entire country. During this large severe weather episode, there were 74 confirmed tornado reports across the Upper Midwest and Northern Plains, including four EF-4 tornadoes. This high count marked the busiest tornado day for the U.S. since 23 May 2008 and one of the largest tornado outbreaks to occur across the region in the past decade.

#### 3) México—V. Davydova-Belitskaya and F. J. Romero-Cruz

The year 2010 was a unique year for México. According to the National Meteorological Service, nationally-averaged annual mean temperature was about 21.0°C, only 0.3 °C above the normal temperature of 20.7°C (Fig. 7.7a). However, for precipitation,

showed a reversal in U.S. temperature conditions even while Canada remained consistently warm; April–September 2010 was very warm across the eastern U.S. and cold across the West. As a further testament to intense seasonal temperature variability over the U.S., fall 2010 saw a sharp turn to cold conditions in the East and the Gulf Coast region.

**A Persistent Phase of the North Atlantic Oscillation during 2010**

A notable extreme climate event during 2010 was the intense negative phase of the North Atlantic Oscillation (NAO), with the annual mean value of the Jones NAO index ranking as the most negative in historical record, which began in 1823. This negative phase is indicative of high latitude blocking, which was a prevailing feature during all seasons. The middle panels of Fig. 7.5 show the seasonal surface temperature signals attributable to the seasonal NAO index of 2010 based on regression analysis. The best agreement between observations and the NAO signal occurs over eastern North America. In particular, the Canadian warmth juxtaposed with the southeast U.S. cold during winter and fall seasons can be largely reconciled with a meridional dipole pattern of NAO-related temperature anomalies, features linked with persistent atmospheric blocking that extended from eastern Canada across Greenland.

**A Sharp Reversal in the ENSO During 2010**

Strong El Niño conditions prevailed over the tropical Pacific from January to March 2010, which swiftly transitioned to moderate La Niña conditions by early summer and continuing into fall. In light of ENSO's known impact on North American climate conditions, it is reasonable to inquire whether the strong seasonality in contiguous U.S. temperatures may have been linked to this abrupt swing of the ENSO cycle. We calculated the ENSO impact on 2010 North American temperatures using a regression analysis and combined that signal with the NAO signal of 2010, the result of which is shown in the right panels of Fig. 7.5. For North America as a whole, the spatial correlation of the observed anomalies and this combined signal is 0.7, 0.7, 0.8, and 0.8 for the winter, spring, summer, and fall 2010 seasons, respectively. What emerges clearly from this diagnosis is the dominant effect of the persistent NAO in generating cold eastern U.S. conditions in early and late 2010, with some indication that the reversal to warm summer conditions in the eastern U.S. was partly due to the region's sensitivity to La Niña conditions, which had emerged with considerable vigor by July 2010.

By no means are all the seasonal features of 2010 North American temperatures interpretable as a signal of NAO variability. In particular, the spatial scale and intensity of the observed Canadian warmth was considerably greater than one would have expected from NAO and ENSO relationships. An important research task is to ascertain the effect of other modes of variability and boundary forcings on North American conditions of 2010, including the state of global sea surface temperatures, sea ice, and anthropogenic greenhouse gas forcing.

## SIDEBAR 7.2: BILLION DOLLAR U.S. WEATHER DISASTERS: 2001–10 —A. SMITH

The U.S. sustained 47 weather-related disasters over the 2001–10 period in which overall damages/costs reached or exceeded $1 billion (U.S. dollars; Fig. 7.6). The total normalized losses (i.e., insured and uninsured loss) for the 47 events exceed $350 billion. The following is a comparison of the disaster loss record for U.S. severe thunderstorms, winter storms, hurricanes, wildfires, flooding, and drought in 2010 against the full 2001–10 period.

Severe thunderstorm losses totaled $10.8 billion in 2010 alone—the highest annual value in the 2001–10 period. During the period, the U.S. annual loss average was $7.1 billion. Since 1980, there has been a pronounced trend in the amount of thunderstorm losses in the contiguous United States. Studies by reinsurer Munich Re have shown a quadrupling of U.S. losses associated with tornado, and hail and high wind damages occurred since 1980 (Hedde 2010). A number of research papers demonstrate that much of this increase is driven by socioeconomic factors such as increases in wealth and population (Changnon 2001; Diaz and Murnane 2008).

Winter storm losses in 2010 were the fifth highest ($1.2 billion), behind 2003, 2007, 2005 and 2004. The average loss for the 2001–10 period was $1.3 billion.

There were no U.S. land falling hurricanes in 2010; therefore, the $185 million worth of losses was well below the 2001–10 loss average of $25.7 billion. The 2001–10 period was punctuated by 2004 and 2005 hurricane seasons, where numerous hurricanes formed and made landfalls over many parts of the South and Southeast region and caused extensive damage.

The 2010 wildfire season was below normal for the number of wildfires reported (71 839) nationally, which was slightly below the 10-year average (78 352). However, the number of hectares burned in 2010 (1 385 169) was well below the 10-year average (2 820 186 hectares). The middle years of the decade represented the highest number of hectares burned—2006, 2007, 2005, and 2004. However, the location of wildfires near the urban-wildland interface is the driving issue on losses and increased firefighting costs. Namely, 2000, 2002, 2003, and 2008 were years in which firefighting costs and fire damages together annually exceeded $2 billion—well above the 2001–10 annual cost/loss average ($750 million).

An estimated $3.2 billion in flood losses occurred in 2010, which was above the 2001–10 annual average of $2.4 billion. These estimates do not include storm surge or inland flooding associated with hurricanes. In late March 2010, the Northeast experienced a severe flooding event. Heavy rainfall over portions of the region caused extensive flooding across the states of Rhode Island, Connecticut, Massachusetts, New Jersey, New York, and Pennsylvania. The event caused the worst flooding in Rhode Island's history and resulted in over $1.5 billion in damages/costs. The mid-South flooding event of 30 April–2 May was also significant, as flooding in the Nashville, Tennessee area alone contributed more than $1 billion in damages. Western and middle Tennessee were the hardest hit, with local rainfall amounts of 460 mm–510 mm to the south and west of greater Nashville. Total losses exceeded $2.3 billion in damages/costs.

While the U.S. drought economic loss numbers are still being finalized, it appears that 2010 was near the 2001–10 average of $1.4 billion. For 2001–10, the most severe drought loss events occurred in 2002, 2006, and 2008, where insured crop losses averaged more than $2 billion. The total cost (e.g., uninsured crop loss and interrupted municipal water services) of drought events may be considerably higher, but difficult to quantify accurately.

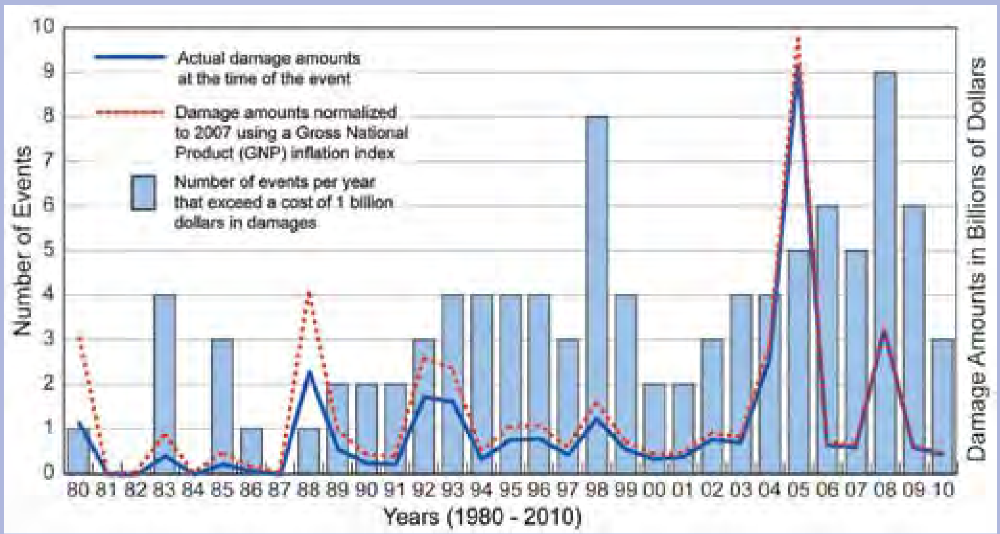


**Fig. 7.6. Billion Dollar U.S. Weather Disasters 1980–2010. (Source: NOAA/NCDC.)**

2010 ranked as the second wettest year since records began in 1941 (Fig. 7.7b). Total amount was about 935.5 mm compared with the normal value of 777.9 mm (1941–2010 average). New monthly records were also reported during the year; 2010 had the wettest February and July, and driest October and December on record.

*(i) Temperature*

The annual mean temperature anomaly ranged from -0.3 to +0.3°C across the country and was considered near normal. The highest positive anomalies in monthly mean temperatures (1.0°C–3.0°C) were recorded in May, June, and August in almost all of the country and in January and December in the northern and northeastern regions. In February and March, there were strong negative anomalies (2.0°C–5.0°C below normal) due to humidity from the Pacific, which brought cloudy skies and heavy and unusual rain. October, November, and December also recorded temperatures below normal as a result of large and dry high pressure air masses in most of the country.

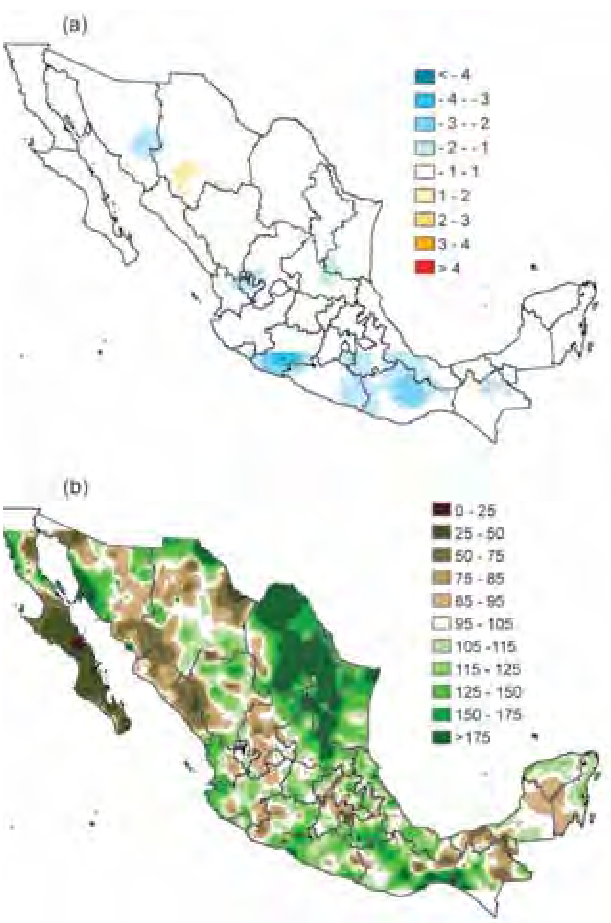


**Fig. 7.7. (a) 2010 annual mean temperature anomalies (°C) for México (based on 1980–2004 mean) and (b) 2010 annual precipitation anomalies (% of 1941–2010 mean). (Source: National Meteorological Service of México.)**

*(ii) Precipitation*

During the first months of 2010, El Niño conditions in the Pacific affected precipitation patterns in northern, northeastern, western, and central regions of México, where heavy winter rains were registered. The accumulated amount during January and February at a national level ranked these months as the third wettest and wettest months, respectively, since records began in 1941.

By July 2010, the transition to La Niña was officially taking place; this climatic event typically strengthens precipitation in the western, central, and southern regions of México. The fast intensification of this event resulted in intense precipitation during July and September in most of country; July registered an estimated 244.2 mm (average is about 140 mm) and was the wettest July on record.

However, autumn was extremely dry. October 2010 was the driest such period on record. The accumulated precipitation estimated at a national level was about 6.7 mm (average is 27.5 mm).

*(iii) Notable events*

Heavy rains, present since the beginning of the year, generated several floods and landslides in many states. The first occurred in February and affected states in the western, central, and southern regions of México. Intense rain up to 200 mm–250 mm was registered from 1 to 5 February in Michoacán and Estado de México. In spite of the damages, dam volumes in the region recovered from a large period of drought conditions, especially those dams that form the Cutzamala system. These had a deficit up to 80% due to the hydrological drought present in the area since the summer of 2009.

In México City and surrounding areas, the accumulated rainfall for the first five days of February was about 57.2 mm (average for that period is about 8.2 mm). As a consequence, some highly populated areas were affected, especially those considered poor zones.

Hurricane Alex created serious damage in México in 2010. The storm impacted Campeche, Tamaulipas, and Nuevo León; thousands of people were affected and millions of pesos were lost in damages. From 30 June to 2 July, the estimated amount of rain was up to 700 mm and caused severe floods as well as some dam overflows in the region. The maximum 24-hour accumulated rainfall was registered in the Pedro Méndez dam in Tamaulipas (399.7 mm) and in the La Boca dam in Nuevo León (389.9 mm).

During the second half of August, there were several tropical depressions, which brought intense rain along the southern Pacific coast. Maximum 24-hour precipitation of 360 mm was registered in the mountains of Oaxaca (Cerro de Oro), which caused a landslide and some lives were lost.

Although August 2010 was classified by the National Meteorological Service as the eighth wettest August in 70 years of record keeping, precipitation registered in Chiapas, Oaxaca, Tabasco, and Veracruz caused several damages to the infrastructure and populations of these states.

In September, the government of Veracruz reported damages due to the floods in the region of the Papaloapan river basin; the floods were caused by the continuous precipitation registered from August through the first half of September. During this period, Hurricane Karl affected 114 counties in the state of Veracruz due to strong winds and heavy rain (up to 350 mm in 24 hours in some regions). Two weeks after Karl, the southern region of Veracruz had another impact, this time from the remnants of Tropical Storm Matthew (24–28 September). The station in Coatzacoalcos registered 411.9 mm in 24 hours on 27 September.

### *c. Central America and the Caribbean*

#### 1) Central America—J. A. Amador, E. J. Alfaro, H. G. Hidalgo, and B. Calderón

For this region, eleven stations were analyzed from the following six countries: Belize, Guatemala, Honduras, Nicaragua, Costa Rica, and Panama.

##### *(i) Temperature*

On the Caribbean side, the year 2010 was warmer than average since it showed a clear pattern of small positive departures with respect to both the 1971–2000 climatology and the last decade (Fig. 7.8). This result appears to be consistent with the persistence of positive sea surface temperature (SST) anomalies in the tropical North Atlantic throughout the year. In contrast, 2010 behaved differently on the Pacific side, where most stations presented a shift to the left in the 2010 distribution, possibly associated with the influence of La Niña conditions in that region. Most stations on the Caribbean side also showed a warmer 2000–09 decade than their corresponding climatology. Two stations on the Pacific side, in southwestern Central America [Tocumen (Tm6) and David (Tm7)], shared the same characteristics as those on the Caribbean side. The other stations indicated a complex behavior with a shift to the left in the 2000–09 distribution (a cooling effect) in Liberia (Tm8) and practically no significant temperature departures at the other two stations [Cholutera (Tm9) and San Jose Tm10)].

Since many stations have a large amount of missing data in their daily minimum ($T_{min}$) and maximum temperatures ($T_{max}$), these two variables were analyzed regionally by taking an average of the five stations on the Pacific side and the five stations on the Caribbean side. On the Pacific side, $T_{min}$ for 2010 indicated small positive departures from the climatology while $T_{max}$ for 2010 indicated small negative departures. On the Caribbean side, $T_{min}$ and $T_{max}$ were slightly warmer than the last decade average but substantially warmer than their climatology.

##### *(ii) Precipitation*

The start date (SD) and end date (ED) of the rainy season were calculated at all selected rain-gauge stations. The SDs observed during 2010 were considered near normal when compared with to those of the 1971–2000 climatology and 2000–09 decade (Fig. 7.8). The 2010 EDs were early at each station except Tocumen (P6) when compared to the climatology; however, compared to the 2000–09 average, almost all stations had a late ED, except David (P7).

All stations located on the Caribbean side showed that the accumulated precipitation for 2010 was below the 1971–2000 average, except for Tocumen (P6). On the Pacific side, accumulated values for 2010 were greater for Tocumen (P6), David (P7), and San Jose (P10) when compared to 1971–2000 and less for Liberia (P8) and Choluteca (P9).

##### *(iii) Tropical cyclone activity*

The year 2010 was very active for tropical storms in the Caribbean basin. By July 2010, La Niña had developed and winds associated with the Caribbean low-level jet were much weaker than normal, an attribute of ENSO cold events in the region and a condition favorable for tropical cyclone development, in addition to the persistent warm SST anomalies observed in the Caribbean and the tropical North Atlantic. There were 13 named storms in the Caribbean (19 in the Atlantic), with seven hurricanes (12 in the Atlantic), and three major hurricanes (five in the Atlantic). Typical observed values, given by the median, in the Caribbean during the last four decades are four named storms, two hurricanes, and one major hurricane. Additionally, some tropical cyclones landed or reached positions close to the Caribbean Central American coast: Alex (25 June–2 July), Karl (14–18 September), Matthew (23–26 September), Paula (11–15 October), and Richard (21–26 October). Important impacts were reported associated with Tropicasl Cyclone Nicole (28–30 September) and Hurricane Tomas (29 October–7 November). In contrast, tropical cyclones in the Pacific affected the Central American isthmus less; the first cyclone of the 2010 season, Agatha (29–30 May), made landfall near San Marcos, Guatemala, causing considerable damage and impacting the region, mainly in the northern countries of Central America.

### 2) The Caribbean — I. G. García, R. P. Suárez, B. L. Pedroso, V. C. Cancino, D. B. Rouco, A. L. Lee, V. G. Velazco, T. S. Stephenson, M. A. Taylor, J. M. Spence, and S. Rossi

Countries considered in this region include: Cuba, Jamaica, Puerto Rico, and the U.S. Virgin Islands.

#### *(i) Temperature*

For Cuba, 2010 was characterized by warm temperatures, with an annual mean anomaly 0.15°C above normal (1971–2000). The summer temperature neared the 1998 record (1997 and 1998 were the warmest years on record). June was particularly warm, with average temperature more than 1.0°C above normal (Fig. 7.9a). In contrast, the winter months registered below-normal temperatures. December 2010 was the coldest December in 60 years,

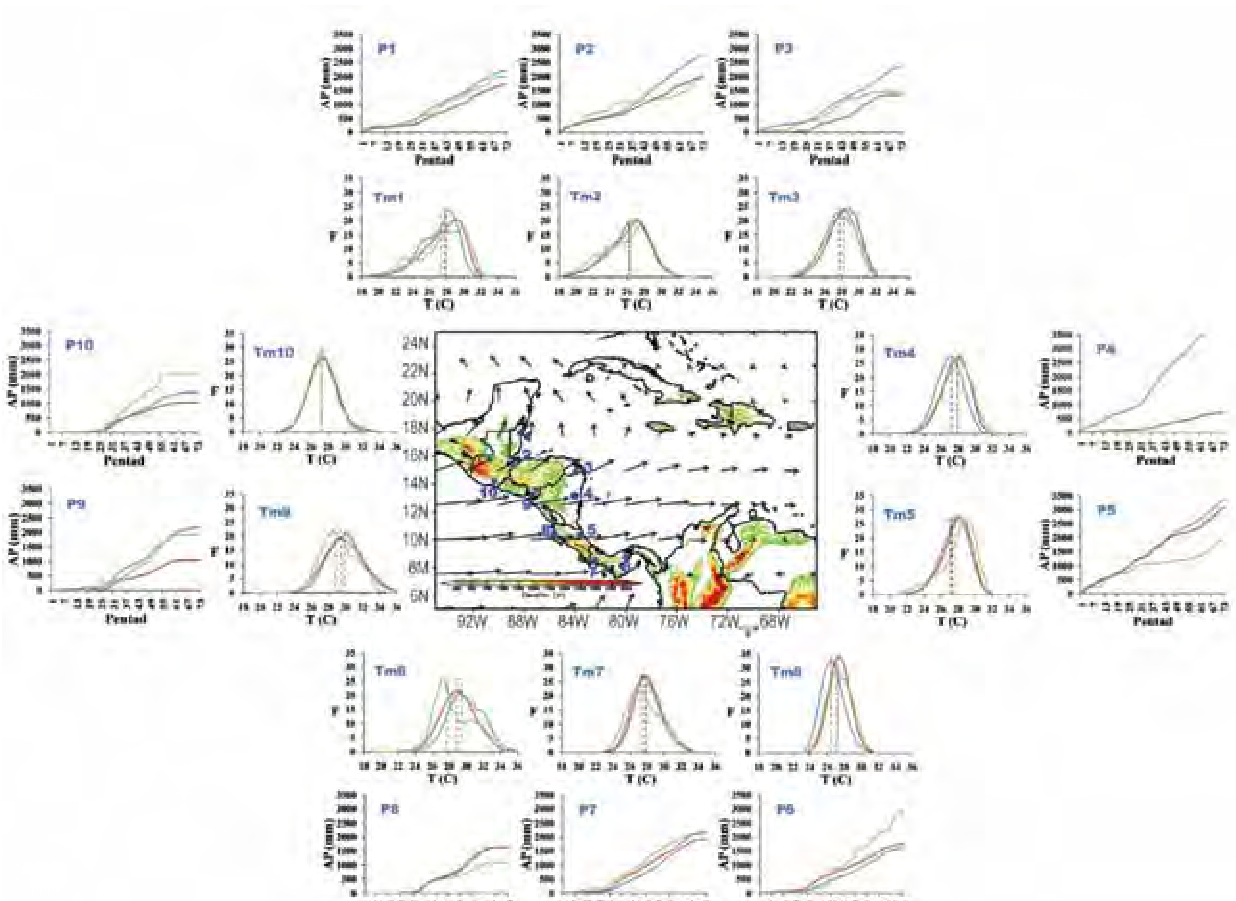


**Fig. 7.8. Location of the 10 stations in Central America: (1) Phillip Goldson Int. Airport, Belize; (2) Puerto Barrios, Guatemala; (3) Puerto Lempira, Honduras; (4) Puerto Cabezas-Bluefields, Nicaragua; (5) Puerto Limon, Costa Rica; (6) Tocumen Int. Airport, Panama; (7) David, Panama; (8) Liberia, Costa Rica; (9) Choluteca, Honduras; and (10) San Jose, Guatemala. Wind anomalies at 925 hPa based on 1958–99 for July. Mean surface temperature frequency (TmN) and accumulated pentad precipitation (PN) are shown for each station N. Blue represents the 1971–2000 average (climatology), red the 2000–09 decade, and green 2010. Note that station 4 does not show 2010 precipitation due to a large number of missing data. (Source: NOAA/NCDC.)**

## SIDEBAR 7.3: SOCIOECONOMIC IMPACTS ASSOCIATED WITH METEOROLOGICAL SYSTEMS AND TROPICAL CYCLONES IN CENTRAL AMERICA IN 2010—J. A. AMADOR

Busy cyclone activities over the Caribbean basin and heavy rainfall heavily impacted Central America in 2010. From 23 to 28 May, a low pressure system affected most of the countries, inflicting damages due to floods in infrastructure, bridges, electrical and water services, and roads. Tropical Cyclone Agatha (29–30 May) struck northern Central America with very heavy rains, resulting in landslides and floods and damages of several millions of dollars (U.S.) in this region. The eruption of the Pacaya Volcano near Guatemala City was an additional factor to heavy rains that accounted for the large number of deaths in Guatemala.

On 20 June, a low pressure system developed about 300 km southwest of Guanacaste Province in Costa Rica, moved northwest and gained hurricane strength (Darby) west of 96°W during 23–25 June, and reached major hurricane status during 25–26 June; however, no major losses were reported due to this system in the region.

Alex (25 June–2 July) formed off of the Caribbean coast of Honduras and acquired tropical storm status on 26 June. As a consequence of rains and floods, six people died in Nicaragua, five in El Salvador, and two in Guatemala. Although Honduras suffered from heavy rains and floods, no human casualties were reported.

From 28 to 30 September, Tropical Storm Nicole affected Costa Rica, Nicaragua, El Salvador, and Guatemala. Main damages were in electrical and road infrastructure, housing, and agriculture. Costa Rica and El Salvador reported $13 million (U.S. dollars) and $2 million (U.S. dollars) in losses, respectively. From 29 October to 7 November, Hurricane Tomas moved slowly over the Caribbean and hit Panama and Costa Rica with heavy and long-lasting rains, leaving these two countries with several human casualties and damages in several important social sectors. On 29 October, a landslide caused by very intense rains near Pico Blanco in Escazu, Costa Rica, left 28 people dead. Nearly 1000 houses were destroyed and economic losses of more that $330 million (U.S. dollars) were reported due to Tomas.

Although some figures are uncertain, Central America was severely impacted by frequent rainfall events and hurricane activity that, in total, left at least 300 people dead and caused more than $2 billion (U.S. dollars) in losses in 2010.

with a monthly anomaly of almost -3.5°C. In December 2010, many Cuban stations broke their all time minimum temperature record.

For Jamaica, some coastal stations recorded above-normal temperatures that corresponded with warmer-than-normal sea surface temperatures around the island for most of the year.

For Puerto Rico, temperatures ranged from 8.3°C on 6 February in Adjuntas to 36.7°C on 25 July in Ponce. By the end of the year, 2010 tied for the eighth warmest year since 1899 across the San Juan metro area, with an average temperature of 27.3°C (the 1971–2000 average is 26.6°C). The year 2010 joins 2007 and 2009 as three of the 10 warmest years since 1899 in the San Juan metro area (Fig. 7.10a).

Across the U.S. Virgin Islands, temperatures ranged from 13.3°C at Beth Upper New Works on Saint Croix, recorded on both 22 and 25 November, to 34.4°C at the Cyril E. King Airport on Saint Thomas, recorded on both 16 June and 24 August. Annual temperatures across the U.S. Virgin Islands were 0.2°C below their 1971–2000 average.

*(ii) Precipitation*

For Cuba, the annual average rainfall for 2010 was near normal. During the rainy season (May–October), the western half of the country was dry with 11% below-

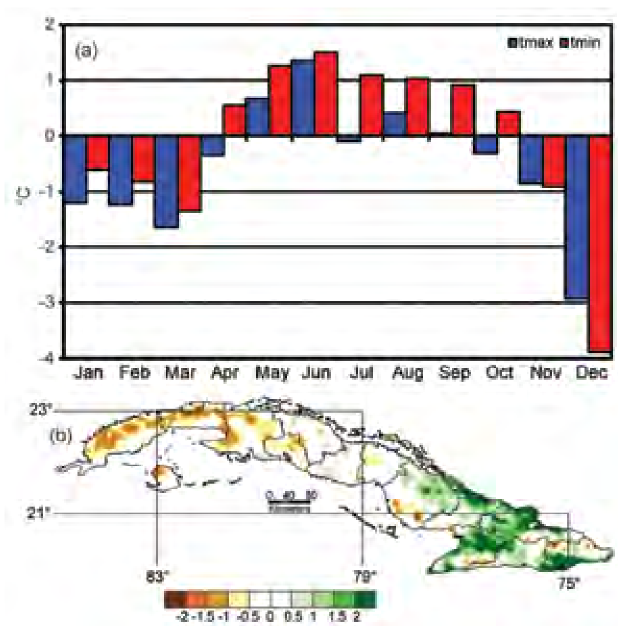


**Fig. 7.9. (a) 2010 monthly mean maximum (tmax) and minimum (tmin) temperature anomalies for Cuba; (b) May to October precipitation anomalies represented as Standardized Precipitation Index (unitless; based on 1971–2000 base period). (Source: Institute of Meteorology of Cuba.)**

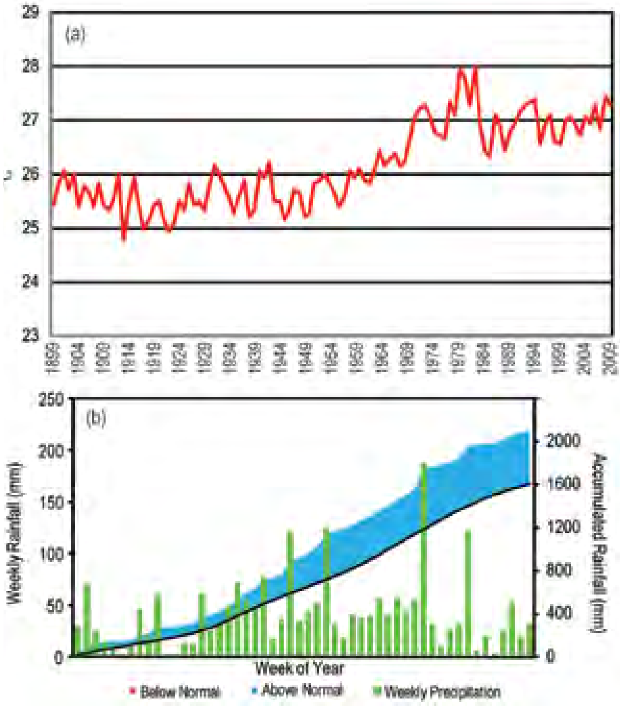


**Fig. 7.10. (a) Annual mean temperature recorded in San Juan's metro area, Puerto Rico; (b) weekly mean rainfall for Puerto Rico, based on over 50 cooperative weather stations, with accumulated rainfall displayed on the right-hand axis of the chart. Year-to-date surpluses are displayed in blue shading. (Source: NOAA/NWS.)**

normal rainfall while the eastern half was wet with rainfall 23% above normal (Fig. 7.9b). During the dry season, the pattern was reversed; the western half of the country was wet (22% above normal) while the eastern half was dry (23% below normal).

For Jamaica, the annual average rainfall for 2010 was above normal in spite of the fact that during the first three months of the year, the island experienced below-normal rainfall. The early rainfall deficit caused significant water shortages as it continued a drying pattern that began in the latter half of 2009 and was associated with persistent El Niño conditions. For April–October, above-normal and near-normal monthly rainfall totals were observed (Fig. 7.11). The transition to wetter conditions was due to a decline in the El Niño state and the onset of La Niña conditions in the Pacific and the associated reduction in tropical Atlantic vertical wind shear. Particularly significant was the 560 mm of rainfall recorded for September which represented the second highest rainfall experienced during this month since records commenced in 1881. All parishes were above normal. The rainfall was primarily due to a broad area of low pressure associated with Tropical Storm Nicole, which was preceded by Tropical Storm Karl in the same month.

For Puerto Rico, due to El Niño conditions and a strong subtropical jet across the Atlantic Basin during the winter months, several cold fronts helped enhance precipitation across both Puerto Rico and the U.S. Virgin Islands during the typical dry season. In addition, with an early start to the tropical season, highlighted by a strong tropical wave that brought record rainfall the weekend of 20 June, numerous rainfall records were broken across the region in 2010. Across San Juan's metro area, a total of 2273 mm of rain was recorded at the Luis Muñoz Marin International Airport during the year, which broke the previous record of 2224 mm recorded in 1931 This total was nearly 1000 mm above the normal annual rainfall of 1289 mm.

Across the U.S. Virgin Islands, a total of 1559 mm of precipitation fell at the Cyril E. King Airport on Saint Thomas during 2010 and a total of 1267 mm of precipitation fell at the Christiansted Airport on Saint Croix. These totals represented the second and seventh wettest years at each site since record keeping began in 1953 and 1951, respectively.

*(iii) Notable events*

May and June 2010 were very warm in Cuba; the percentage of warm nights (night when the minimum temperature is above the 90th percentile) was the highest since 1961. However, December 2010 was very cold and the percentage of cold nights (night when the minimum temperature is below the 10th percentile) was a new record for December.

For Jamaica, the broad area of low pressure associated with Tropical Storm Nicole impacted 133 communities—107 by flooding, 16 by landslides,

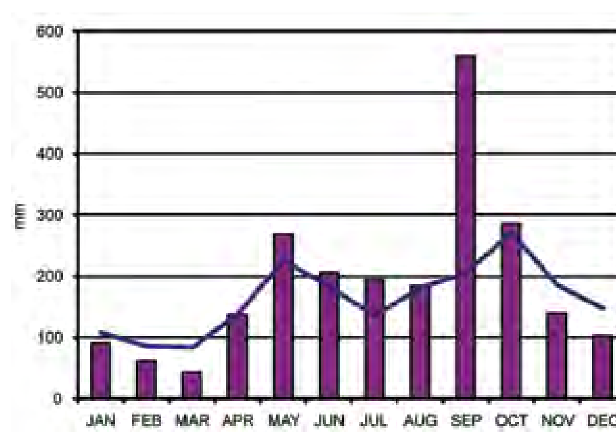


**Fig. 7.11. Monthly Jamaican rainfall for 2010 (purple bars) and long-term average 1951–80 (blue line). (Source: Meteorological Service of Jamaica.)**

one by storm surge, three by unusual storms, and six by wind damage. There were six confirmed deaths. The estimated cost of damages was $10.6 billion (U.S dollars). The agricultural sector was one of the most harshly affected; over $500 million (U.S. dollars) worth of crops were lost during the event.

The typical dry season across the northeastern Caribbean was nonexistent in 2010, with the remnants of several cold fronts bringing persistent periods of wet weather across both Puerto Rico and the U.S. Virgin Islands during the typical dry months of January – April (Fig. 7.10b). This unusually wet start to the year was followed by four significant tropical systems that affected the region. While both Puerto Rico and the U.S. Virgin Islands were spared any direct hits from tropical systems during the 2010 Atlantic hurricane season, three organized tropical systems (Bonnie, Otto, and Tomas) all brought widespread flooding rainfall across the local islands over the course of the season. The fifth wettest day on record at the Cyril E. King Airport on Saint Thomas (168 mm) was recorded on 5 October with the passage of Hurricane Otto and an impressive 547 mm was recorded at Red Hook Bay on Saint Thomas over a period of four days, also with the passage of Hurricane Otto. Across Puerto Rico, an impressive 397 mm of precipitation was recorded along the Rio Portugues in southern Puerto Rico over the same four-day period due to the storm.

### *d. South America*

The 2010 annual mean temperature was near normal to above normal in northern South America and the tropical Andes, and near normal to below normal in Amazonia and most of southern South America (Fig. 7.12a). The annual total precipitation was generally below normal, with significant negative anomalies in Bolivia, Chile, and Argentina; however, significant positive anomalies occurred in Colombia and Venezuela (Fig. 7.12b).

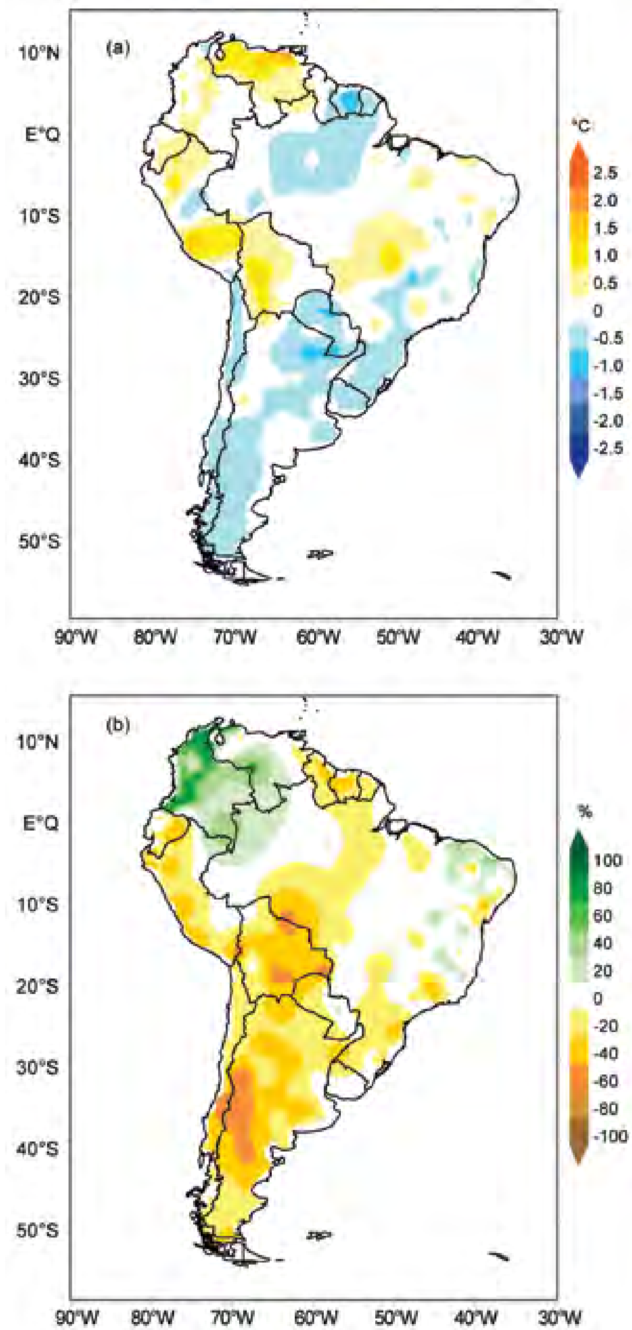


**Fig. 7.12. (a) 2010 annual mean temperature anomalies (°C) for South America (based on 1971–2000 mean) and (b) 2010 annual precipitation anomalies (% relative to 1971–2000 mean). (Sources: National Meteorological Services of Argentina, Brazil, Bolivia, Chile, Colombia, Ecuador, Paraguay, Perú, Surinam, Uruguay, and Venezuela. The data was compiled and processed by International Research Center on El Niño, 2010.)**

#### 1) Northern South America and the Tropical Andes—R. Martínez, C. Euscátegui, E. Jaimes, G. León, and A. Quintero

*(i) Temperature*

The year 2010 was characterized by the occurrence of both ENSO phases: the end of El Niño near the beginning of 2010 and the development of La Niña in mid-2010. The ENSO influence was evident on the temperature of Venezuela, Colombia, and Ecuador but was relatively weak in Peru and Bolivia. Temperature anomalies from +1°C to +1.5°C were observed in Venezuela, Colombia, and Ecuador during the first half of the year. From June to December, temperature was near normal in Venezuela and Colombia, but below normal in most of Ecuador and Peru.

#### *(ii) Precipitation*

In Venezuela, a large precipitation deficit was observed across the country in January–March, which severely affected hydropower generation and agriculture. From April to June, precipitation was near normal and positive anomalies were registered at some locations. In July–September, precipitation anomalies became positive in most of the country. During the last trimester, especially in November, precipitation records were observed at several locations; the highest anomalies were observed in Falcon (over the past 88 years), Maracay (71 years), Barcelona (53 years), and Caracas (45 years). Thousands of people were affected by floods and millions of economic losses were reported.

In Colombia, precipitation deficits of 40%–70% were observed in the Andean and Pacific regions from January to May. In January, the deficit was near 100% at some locations. Dry conditions, along with high temperatures, led to larger-than-usual forest fires. From June to August, precipitation anomalies gradually became positive, generating flash floods and landslides in the central Andean zone and eastern Llanos. The last four months of the year were characterized by significant wet conditions associated with La Niña. In November, positive anomalies from 100% to 300% were registered in most of the country. Although December is usually the month of transition from wet to dry conditions, positive anomalies from 40% to 70% were observed across northern and central Colombia. Floods and landslides generated serious damages and affected more than two million people; 300 000 houses were destroyed, and thousands of kilometers of roads were affected. The year 2010 became the rainiest year in Colombia since the beginning of the instrumental record.

In Ecuador, the El Niño event produced an opposite effect on the precipitation, similar to past El Niño events observed after 1998. From January to April, precipitation anomalies were below normal to near normal. In May, significant positive anomalies from 50% to 70% were observed on the north coast. From June to October, negative precipitation anomalies prevailed along with precipitation deficit from 40% to 70% over the Andean region. From November to December, positive anomalies were observed across the country. Precipitation records have indicated some evidence of the weak influence of ENSO events over Ecuadorian climate, which has been consistent in the last decade.

In Peru, the influence of El Niño was also very weak. From January to March, precipitation was below normal mainly in the northeast of the country and southern highlands with deficits from 60% to 100%. However, during this period, extreme events occurred in Lima, Cuzco, and the northern coast. During April–June, dry conditions prevailed with the exception of northern Peru and southern highlands, where deficits turned to precipitation of 40% to 60% above normal. From July to September, precipitation decreased and deficits up to 100% were observed. During the last four months, precipitation deficits prevailed across most of the country, except for specific locations on the north coast and Cuzco, where positive anomalies up to 60% were observed.

In Bolivia, precipitation patterns changed from month to month from January–March. While February was characterized by positive anomalies in central and south of the country, a deficit up to 50% was observed mainly in the northeast in March. From April to June, precipitation deficits peaked in April in most of the country with anomalies from 50% to 100%. This condition gradually changed to near-normal precipitation in June. From July to September, near-normal precipitation was observed. The last trimester of the year was characterized by below-normal precipitation, although positive anomalies up to 50% were observed in northwestern Bolivia in October.

#### *(iii) Notable events*

In Venezuela, several tornadoes were observed in the municipalities of Buchivacoa and Dabajuro (24 April), Cumana (6 June), El Palotal (22 September), and Palmarito (16 October). These events affected hundreds of houses and more than 256 families.

In Peru, strong precipitation and hail storms in January generated an increase in the stream flow of the Vilnacota River which reached up to 600 $m^3 s^{-1}$ (214% of normal). This flooding interrupted the railway and isolated the Machu Picchu area. Thousands of tourists were evacuated and the area was declared in a state of emergency for 60 days. Seven people died and millions of dollars in economic losses were reported. In April, severe storms affected the Huanuco region, resulting in floods and landslides; 23 people died, and 47 disappeared. In July, extreme low temperatures were observed in central and southern highlands; record anomalies were observed in Junín (-5.7°C), Puno (-7.5°C), and Chuapalca (-8.3°C).

### 2) Tropical South America East of the Andes—J. A. Marengo, L. M. Alves, J. Ronchail, and J. Baez

The year 2010 began with an El Niño event well established in the Pacific Ocean. A rapid transition took place and La Niña was present by July. The La Niña event in 2010 one of the strongest on record. The El Niño-to-La Niña transition was similar to the event occurring in 1998, another very warm year, although El Niño was weaker and La Niña stronger in 2010. The annual mean temperature and total precipitation were mainly near normal across the region (Figs. 7.12a; 7.12b).

*(i) Temperature*

From January to February, the maximum temperature in most of eastern South America was 3°C–4°C above normal. At the beginning of February, a heat wave affected the Brazilian city of Santos in the coastal region of the state of São Paulo, with the temperature reaching up to 40°C and very low relative humidity; 32 elderly people died due to heat exposure. The city of Rio de Janeiro registered peak temperatures of 45°C–48°C and in Porto Alegre in southern Brazil, temperatures were above 40°C. Similar values of 40°C–44°C were also recorded over the Chaco region of Argentina and Paraguay.

From March to April, while the tropical North Atlantic was about 2°C–3°C above normal, maximum air temperature in northern Amazonia and northeastern Brazil was 2°C–4°C above normal. In the city of São Paulo, as well as in the interior of the state, the temperature reached above 34°C in March, breaking the record previously set in 1943.

From May to August, various cold spell episodes occurred in the southern part of South America, reaching the tropical regions of Brazil and Bolivia. The strongest episode was accompanied by heavy snowfall lasting nearly a week (11–18 July). Unusually low temperatures were observed: 4°C in the Bolivian Amazon lowland at Santa Cruz de la Sierra; -3°C in Pratts Gill, west of the Paraguay Chaco; -8°C in the state of Santa Catarina in southern Brazil; and -14°C in the vineyard Bolivian city of Tarija. The lowest temperatures, < -20°C, were recorded in the Peruvian and Bolivian Altiplano, where the density of poor farmers is large. Many people, especially young children and elderly, died from hypothermia, pneumonia, and other respiratory diseases. A state of emergency was declared in the Andean regions of Peru and in the Amazon basin where night temperatures as low as 10°C were recorded along the Madre de Dios and Ucayali rivers when they usually exceed 20°C.

From September to December, temperatures 1°C above normal were observed in regions of eastern South America and temperatures 2°C above normal were observed in northeastern and southern Brazil in November and December. This warming in west central Brazil, northwest of Paraguay and Bolivia, was accompanied by rainfall deficits, which increased the number of fires in these regions.

*(ii) Precipitation*

From January to February, heavy rainfall and floods affected Bolivia and western Amazonia. In the Urubamba valley, mudslides destroyed train tracks and bridges and more than 4000 tourists were trapped in Aguas Calientes, at the foot of the Machu Picchu, Peru. In large areas of the Brazilian states of São Paulo, Rio de Janeiro, and Mato Grosso, rainfall was 100 mm–200 mm above normal in January and February. As a consequence, São Paulo and Rio de Janeiro were affected by floods, leaving thousands of people homeless. In Mato Grosso, more than 20 000 people were isolated due to floods in February, and the Cuiaba River in the Pantanal region experienced the largest flood in the last 15 years. A similar situation occurred in northern Paraguay, south of the Pantanal basin, where, over the Vallemí, 200 mm of rainfall was observed in an eight-hour period, affecting 300 families. Most of the rainfall anomalies in January and February were due to the presence of an upper level cyclonic vortex over northeastern Brazil, which, together with the El Niño phenomenon, also inhibited rainfall over the Northeast Brazil region until April.

Drought conditions were detected in eastern and northern Amazonia, with between 100 mm and 200 mm below-normal precipitation in January 2010, and by February and March, the deficit extended all the way to central Amazonia. More than 200 mm below-normal precipitation was found over the mouth of

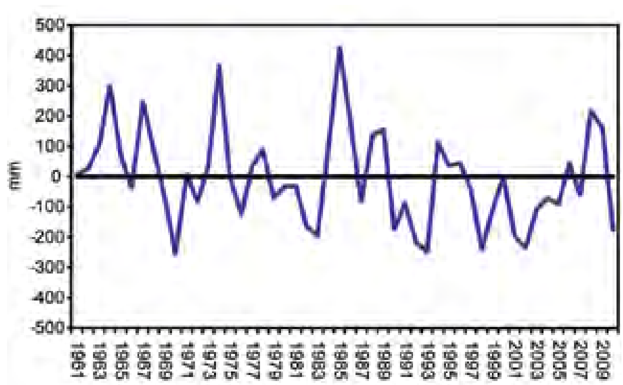


**Fig. 7.13. Annual precipitation anomalies (mm) for the semiarid regions of northeastern Brazil (10°S–5°S, 45°W–38°W) during the peak of the rainy season Feb–May (based on the 1961–2010 long-term average of 541 mm). (Source: National Institute for Space Research, Brazil.)**

the Amazon River and in northeastern Brazil. From March to May, the rainy season in northeastern Brazil was relatively weak and rainfall was 100 mm–150 mm below normal, becoming the fourth driest season in the last 40 years (Fig. 7.13).

From July to September, the unusually dry period in northwestern Brazil, along with rainfall 100 mm below normal, resulted in reduced stream flow in many parts of the Amazon catchments; the Rio Negro, a major Amazon tributary, fell to its lowest level on record—13.63 m—in Manaus in October. See Sidebar 7.4 for more details on the Amazonian drought.

## SIDEBAR 7.4: THE DROUGHT OF AMAZONIA IN 2010—J. A. MARENGO AND L. M. ALVES

After the drought of 2005, drought struck the Amazon region again in 2010. Drier-than-normal conditions were observed in northwestern, central, and eastern Amazonia during austral summer and the rest of Amazonia until the end of the year. Below-normal rainfall and warm temperatures affected the water level of the Rio Negro River, which reached its lowest level since record keeping began 107 years ago. The drier conditions also favored the forest fires in southern Amazonia; the number of fires reported by September was about 200% higher compared to 2009.

The drought started during El Niño and became more intense during La Niña. Some previous droughts in Amazonia were associated with El Niño; however, in 1964, 2005, and part of 2010, the droughts were also associated with warmer-than-average sea surface temperatures in the tropical Atlantic Ocean north of the Equator. From March to April 2010, the sea surface temperature in this region was about 2°C–3°C above normal while it was only 1°C–2°C above normal during the same season in 2005. The droughts of 2005 and 2010 were similar in terms of meteorological severity; however, the hydrological impacts of the drought in 2010 were more extensive with respect to water levels. In addition, the seasonal rainfall anomalies indicate drier-than-expected conditions almost the entire year (Fig. 7.14).

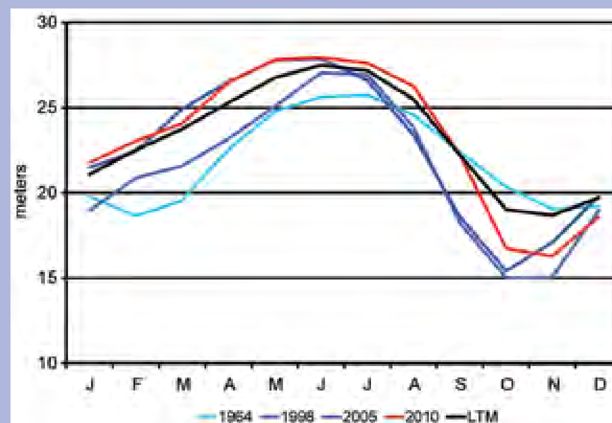


**Fig. 7.15. Monthly levels of the Rio Negro in Manaus, Brazil, for some extreme dry years (1964, 1998, 2005, and 2010) as compared to the 1903–86 long-term average. (Source: CPRM-Manaus, Brazil.)**

The levels of the Rio Negro River, which flows near Manaus in the northern part of the basin, were lower than the levels of the previous drought in 2005 at the beginning of the year; the water levels recovered by May–September, then dropped again to a record low in October–November (Fig. 7.15). On 24 October, the Rio Negro River reached its all time low of 13.63 m at the Manaus site, edging 1963 when water levels reached 13.64 m, according the Geological Survey of Brazil. For the Rio Madeira River, located in the southern part of the Amazon basin, the levels during 2010 were closer to previous records during the drought of 2005.

Transportation, fishing activity, and water supply in the region were affected due to the anomalously low river levels. Local newspapers in Manaus reported that fishing production dropped due to the drought.

The Amazon is periodically subject to floods and droughts, but the recent droughts of 2005 and 2010 and floods of 2009 draw attention to the vulnerability today's climate extremes impose on human populations and the ecosystems upon which they depend.

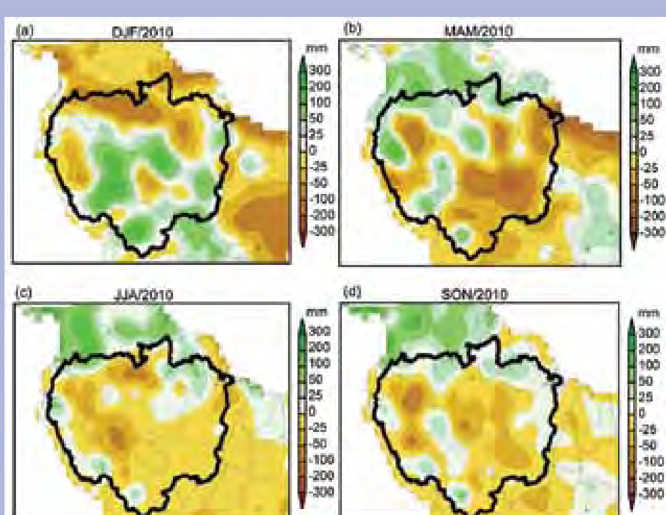


**Fig. 7.14. Seasonal rainfall anomalies (mm) in tropical South America for (a) Dec 2009–Feb 2010; (b) Mar–May 2010; (c) Jun–Aug 2010; and (d) Sep–Nov 2010 (based on 1951–2000). (Source: GPCC.)**

From October to December, drier-than-normal conditions continued across the region. In the Chaco sector of Paraguay, especially in the central and western parts, rainfall deficits were severe, particularly when only one day of rain was recorded in central of Paraguay.

3) Southern South America—M. Bidegain, M. Skansi, O. Penalba, and J. Quintana

*(i) Temperature*

Near-normal to slightly-below-normal temperatures were observed over most of southern South America during 2010, with anomalies ranging between -0.5°C and +0.0°C (Fig. 7.12a). During austral summer (January–February 2010), positive anomalies were observed in northern Argentina, Uruguay, and central Chile. This behavior was accompanied by positive minimum temperature anomalies and heavy rainfall during El Niño. Furthermore, northern Argentina was affected by a warm air mass, bringing the highest minimum temperature on record since 1961. However, in February, Patagonia, Rio Gallegos, and San Julián in southern Argentina, and Coyahique and Balmaceda in Chile recorded very low temperatures, leading to the coldest February in the past 50 years.

The Southern Hemisphere autumn (March–May) showed positive temperature anomalies over Uruguay and central Chile and negative anomalies over northern Argentina and Paraguay.

During austral winter (June–August), negative temperature anomalies were observed over the entire region, and July and August were the coldest months with anomalies of -0.5°C to -2.0°C. Below-average temperatures were widespread across southern South America in July. In Chile, negative anomalies of -2.0°C were registered for both minimum and maximum temperatures. According to the Argentinean Meteorological Service, temperature anomalies of 2°C–3°C below average were observed across Argentina in July. A cold snap during the middle of the month brought temperatures 12°C below average for several days. This cold wave affected Paraguay, Uruguay, Bolivia, Chile, Brazil, and Peru. Minimum temperatures, as low as -24°C, were reported in the Andes Mountains. Several deaths were reported in Argentina, Uruguay, Paraguay, and Bolivia as direct or indirect consequences of these low temperatures. This invasion of cold air covered half of the region with snow, from Cuyo region (northwestern Argentina) to the south of Buenos Aires, where snow is rare.

During the austral spring (September–November), negative mean temperature anomalies remained in northern Argentina while positive anomalies were observed over central Chile and the Patagonia region of southern Argentina.

*(ii) Precipitation*

Annual total precipitation was generally below normal across the region (Fig.7.12b). During January and February (austral summer), positive precipitation anomalies in southeastern South America were driven by the El Niño event; the regions most affected by the rains were eastern Argentina, Uruguay, and southern Brazil.

During the first week of February, extreme rainfall took place in the center of the Uruguay, Entre Ríos (eastern Argentina), and northeast of the province of Buenos Aires. Flooding affected the Negro river basin in Uruguay and the maximum accumulated seven-day total was recorded in Algorta (Department of Paysandú) with 467 mm. February was quite rainy for Uruguay, not only for record rainfall amount but also with respect to the number of rainy days, which ranged between 13 and 15 days in many places (average is 6 to 9 days).

During the second half of 2010, negative sea surface temperature anomalies generated negative rainfall anomalies in southern South America, mainly during October–December. Central and southern Chile were dominated by rainfall deficits of 30%–50%. Eastern Argentina, Uruguay, and southern Brazil experienced below-normal rainfall during these months, which caused damage to agriculture and cattle farming. These conditions exacerbated the water shortage for summer crops (soybean, maize, and rice) and pastures.

Intense rainfalls were also observed in Uruguay in September, causing serious floods that displaced about a thousand people in various areas of the country, led to 16 road closures, and caused at least two deaths. The regions of Agosto and Santa Lucia were the most affected.

*(iii) Notable events*

An intense cold front, moving through Bariloche city (Argentinean side of Andes Mountain) and its surroundings, brought a drop in minimum temperature to 4°C along with rain, freezing rain, and snow on mountains peaks above 1500 meters. This unusual event occurred from January to February and last occurred three years ago.

On 6 January, in the Tucumán province of northern Argentina, 75 km $hr^{-1}$ winds and heavy rain were observed, causing rivers to overflow and stranding the affected population. In Cordoba, rainfall totals of 175 mm within a few hours led to severe flooding that destroyed bridges.

In February, heavy rains were recorded in the province of Entre Ríos in eastern Argentina, the northeastern region of Buenos Aires province, and Uruguay. Monthly totals exceeded 600 mm locally, leading to anomalies greater than 400 mm. All-time monthly records were broken in several locations. Monthly totals of 469.1 mm in the Entre Rios city of Concordia and 420.3 mm in the city of Buenos Aires were the highest February rainfall amounts for those cities since records began in 1903 and 1861, respectively (Table 7.1).

On 18 April, a heavy hail storm hit the northeastern region Buenos Aires province, causing considerable damage in some areas( with hail 5 cm in diameter).

On 10 July, the Aysen region (46°S) of Chile was affected by extreme snowfall associated with a cold front. Accumulation of more than 1 m of snow caused severe damage to agriculture and livestock. Prior to 2010, this weather phenomenon—called "white earthquake"—last occurred in 1995.

**Table 7.1. Record February 2010 precipitation for select locations in Uruguay and Argentina.**

| Location | Precipitation February 2010 (mm) | Previous record (mm) and year of occurrence | Reference period |
|---|---|---|---|
| Young (URU) | 631.0 | 528.2 (1984) | 1931–2009 |
| Durazno (URU) | 543.0 | 467.0 (1977) | 1931–2009 |
| Melo (URU) | 531.5 | 461.3 (1990) | 1931–2009 |
| Tacuarembo (URU) | 502.3 | 350.1 (2003) | 1931–2009 |
| Concordia (ARG) | 469.1 | 404.4 (1984) | 1903–2009 |
| Buenos Aires (ARG) | 420.3 | 403.3 (2003) | 1861–2009 |
| Punta Indio (ARG) | 349.0 | 310.9 (1958) | 1925–2009 |

## SIDEBAR 7.5: SAND PRECIPITATION REACHES RIO DE LA PLATA IN JULY 2010—M. BIDEGAIN AND M. SKANSI

On 18 July, strong winds whipped thick clouds of dust across the Bolivian highlands. Much of the pale dust originated from small salt pans (dry lake beds) south and southwest of Salar de Uyuni. In La Quiaca, a town 3462 m above sea level, the wind reached 95 km $hr^{-1}$ for many hours and, combined with the sand, reduced visibility to less than 100 meters. A high-resolution satellite image on 19 July (Fig.7.16) shows the sand (brown color) on the edge of the cloud layer. The strong winds associated with the movement of a cold front carried the dust from Bolivia to Buenos Aires, Argentina, and southern Uruguay. Mixed with clouds, sand precipitated along with the rain in these regions because of the low pressure system instability in central and northern Argentina, Uruguay, and southern Brazil.

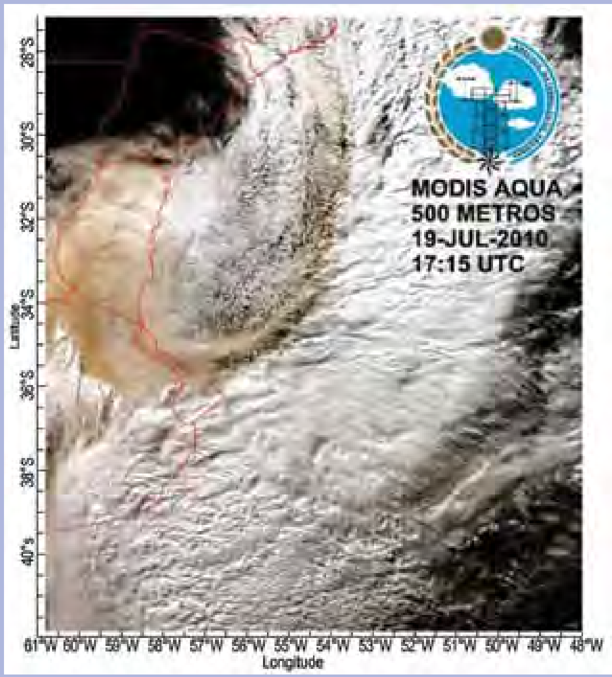


**Fig. 7.16. Aqua MODIS satellite imagery of dust over Rio de la Plata on 19 Jul 2010. (Source: Servicio Meteorológico Nacional-Argentina).**

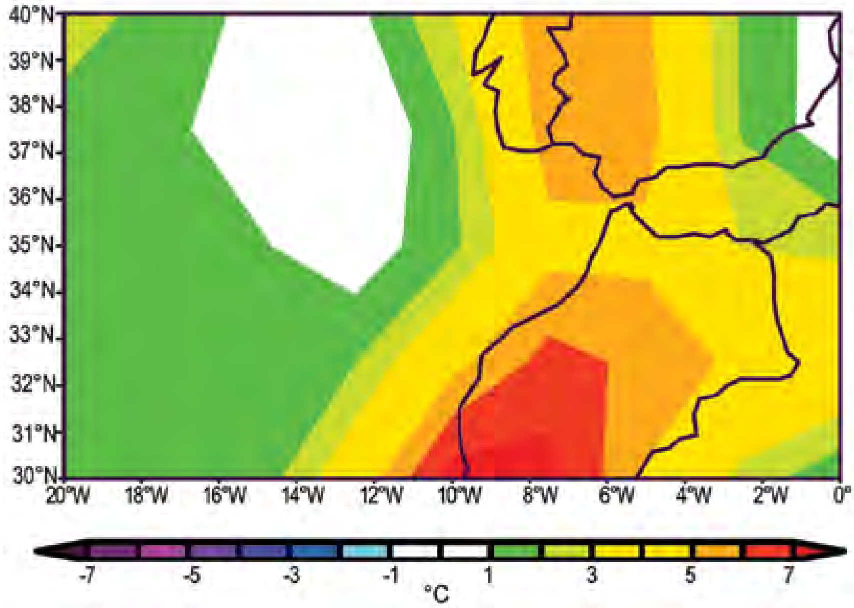


**Fig. 7.17. Daily maximum temperature anomalies (°C) on 29 Aug 2010 for Morocco (based on 1971–2000). (Source: NOAA/ESRL.)**

## e. *Africa*

### 1) Northern Africa—K. Kabidi, A. Sayouri, S. M. Attaher, and M. A. Medany

Countries considered in this region include Morocco, Algeria, Tunisia, and Egypt.

#### *(i) Temperature*

The year 2010 was an exceptionally warm year in northern Africa. Annual temperature was 1.0°C–3.0°C above normal in most regions (based on 1971–2000 base period). The warmth was influenced by extreme temperatures, which were reported mainly during the summer. The annual mean temperature anomaly was between +0.1°C and +2.5°C in Morocco. Winter was relatively warm, with monthly minimum temperature anomalies exceeding +3.5°C in the northern Atlantic region. During summer, exceptional heat waves were frequent and strong monthly anomalies were recorded, for example, +3.5°C in August in the northern Atlantic city of Larache. During July and August, the daily maximum temperature reached 46°C in some parts of Algeria and 45°C in many parts of Morocco. The daily temperature was more than 5°C above normal on 29 August for most of Morocco (Fig. 7.17). Some locations set their record-high daily temperatures in 2010: 42°C in Ouarzazate (24 July); 45.8°C in Rabat (26 August); and 45.4°C in Taza (27 August).

In Egypt, the 2010 annual mean temperature was remarkably warm, with an anomaly of +2.9°C (Fig. 7.18). The annual mean maximum and minimum temperature anomalies were +1.4°C and +4.8°C, respectively. All weather stations around Egypt indicated above-average annual minimum temperature anomalies, varying from +0.6°C to +10.1°C. Stations located on the northern coast experienced annual mean temperature anomalies ranging from +0.2°C to +1.3°C, whereas anomalies varied from +1.0°C to +6.9°C in Middle and Upper Egypt. While northern Egypt experienced an annual maximum temperature of about 2°C below average, the rest of the country was 1.1°C–7.5°C above average.

#### *(ii) Precipitation*

Very wet conditions were recorded during 2010 in North Africa; winter and autumn were characterized by episodes of intense rainfall and floods. Heavy rainfall exceeded the monthly average by more than 500% for most locations over the region. Storms occurring from 27 to 30 November caused heavy rains exceeding 150 mm in six hours in the Moroccan cities of Chefchaouen (175 mm) and Casablanca (172.8 mm),

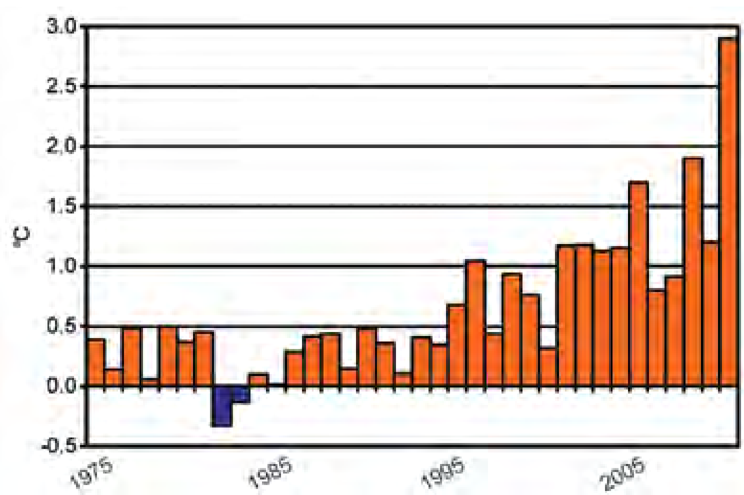


**Fig. 7.18. Annual mean temperature anomalies for the period 1975–2010 (based on 1961–90 mean) for Egypt. (Source: Egyptian Meteorological Authority.)**

resulting in floods in many parts of the northwest region. From September to December, the rainfall amount was more than 2.5 times higher than average at many locations (e.g., 804 mm in Chefchaouen, 761 mm in Ifrane, 508 mm in Larache, 438 mm in Casablanca, and 422 mm in Rabat).

*(iii) Notable events*

October and November were marked by significant heavy rainfall, leading to several floods in Morocco, Algeria, and Tunisia. These events caused major infrastructure damage and deaths.

Many 24-hour rainfall records were broken during the year: 92 mm in Nador (25 January); 75.3 mm in Taroudante (16 February); 66.9 mm in Tanger Port (15 September); 98.9 mm in Tetouan (29 November); 175 mm in Chefchaouen (29 November); and 86.9 mm in Taza (29 November).

According to the High Commission of Waters and Forests of Morocco, almost 500 hectares were destroyed by several forest fires in the extreme north during July and August; the Chefchaouen region was the most affected, especially during the heat wave when daily temperature exceeded 47°C.

### 2) Western Africa—L. N. Njau and W. M. Thiaw

Western Africa extends from the Guinea coast to Chad and the Central African Republic.

*(i) Temperature*

The year 2010 was exceptionally warm in Western Africa. The monthly temperature remained above average for every month and across the region. In January, the temperature was 1.5°C above normal and the greatest anomalies (3.5°C above the reference period 1971–2000) were observed in Mauritania, central Niger, and northern Sudan. The positive

## SIDEBAR 7.6: ADVERSE WEATHER IN EGYPT—S. M. ATTAHER, M. A. MEDANY

At the beginning of 2010, from 15 to 20 January, Egypt was hit by heavy rains exceeding 80 mm day$^{-1}$, leading to the worst flash floods since 1994. The floods affected the Sinai Peninsula, Red Sea coast, and Aswan Governorate in Upper Egypt (Fig. 7.19), causing 15 deaths, 780 destroyed homes, and 3500 evacuations. Material losses were estimated at $25.3 million (U.S. dollars).

near the end of 2010, from 12 to 15 December, adverse weather conditions, including snow, rain storms, and strong winds swept across Egypt, causing fatalities, extensive material damage, and disruption to ports and airports. The storm, which caused temperatures to plunge to below freezing in some places and wind speeds to reach 60 km hr$^{-1}$, ended weeks of unseasonably warm and dry dust storms. Eighteen people were killed and 59 injured in traffic accidents associated with the bad weather, and a factory building collapsed in Alexandria. The storm closed several ports and airports and disrupted traffic in the Suez Canal.

Climate disaster risk management in Egypt is currently facing several challenges. Accurate and detailed information regarding the impact of extreme climate events is very limited. Further, effective forecasting tools and early warning systems for these events are not yet available to national meteorological and research authorities. There is an urgent need to study the impact of extreme events on different sectors and activities, establish accurate and detailed statistics and records, and develop forecasting tools and early warning systems to reduce harmful impacts.

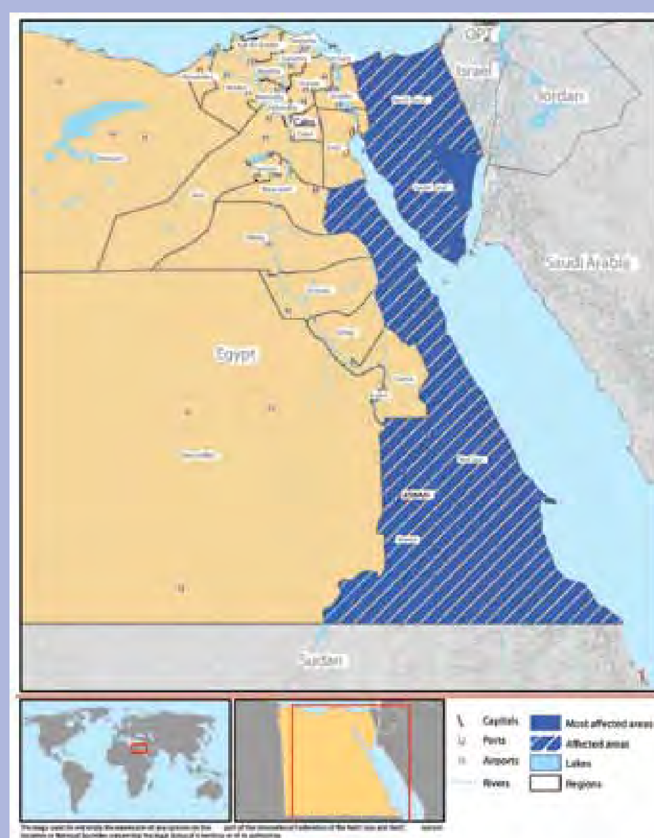


**Fig. 7.19. Areas affected by flash floods in Egypt in the middle of January 2010. Source: Flash Floods DREF operation no. MDREG009 Final Report, International Federation of Red Cross and Red Crescent Societies (IFRC).**

anomalies increased in February, with temperatures 3.5°C above average in northern Sudan, Chad, Niger, central Mali, and southeast Mauritania. In March, the temperature declined but was still 1.5°C above normal. The anomalies remained at +1.5°C in April, with the highest departures from normal (> 3.0°C) over Mali and northeastern Mauritania. In May, temperature was also generally 1.5°C above average, with the highest anomalies (> 2.5°C) over northern Nigeria and southern Niger. The temperature declined tremendously by midyear, becoming near normal in June, July, August, and September. However, very warm temperatures returned in October, with temperature anomalies of +2.5°C to +3.0°C over northern Niger. In November, positive temperature anomalies (> 2.5°C) were observed over the eastern part of the Sahel. In December, very warm temperatures continued, with anomalies of +3.0°C covering Mauritania and northern Senegal. Many people died from heat stress in this region in 2010.

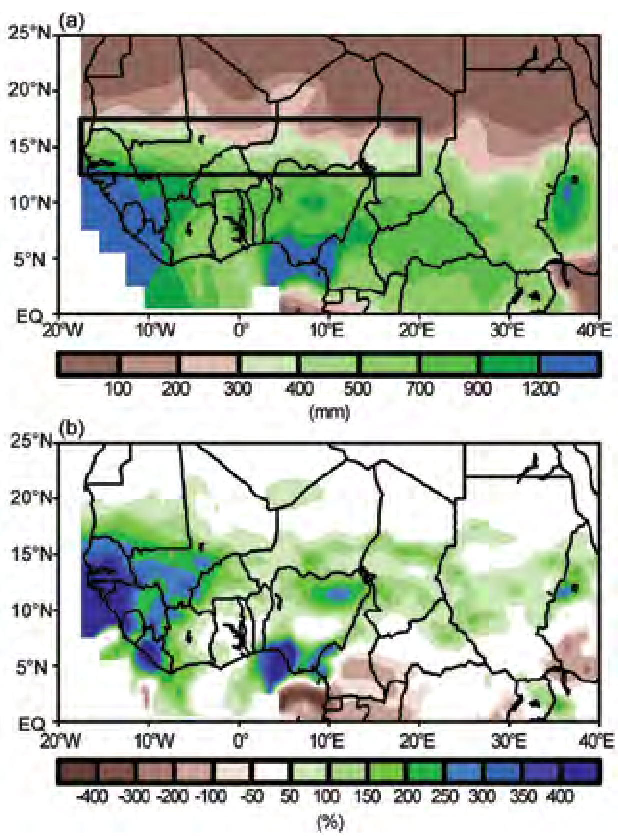


**Fig. 7.20. June–September 2010 (a) rainfall (mm) for Western Africa and (b) anomalies (% of 1971–2000 base period). The boxed region indicates the approximate boundaries of the Sahel region. (Source: NOAA/NCEP.)**

*(ii) Precipitation*

The year 2010 was characterized by very wet conditions in Western Africa. Rainfall totals from June to September ranged between less than 100 mm in the northern part of the Sahel to over 1200 mm in the western Guinean coast, southern Nigeria, and northwest Cameroon (Fig. 7.20a). The rainy season was above average across the Sahel and portions of the Gulf of Guinea. In the Sahel, it was the wettest season since 1958. Specifically, rainfall surpluses ranged between 50 mm and 100 mm across the Sahel in June and moisture was sustained throughout the season, exceeding 150 mm above average in portions of the western Sahel in September. South of the Sahel, rainfall surpluses exceeded 200 mm over southern Mauritania, and ranged between 250 mm and 350 mm over northern Senegal and parts of Mali. Rainfall surpluses exceeded 400 mm from southern Senegal to western Guinea and along the Nigerian southwestern coast (Fig. 7.20b). The rainfall extremes that soaked the Sahel, especially in the west, resulted in flooding, loss of life and property, and damages to infrastructure in many places, including Senegal, Guinea, and Mali.

*3) Eastern Africa* —C. Oludhe, L. Ogallo, P. Ambenje, Z. Athery, and W. Gitau

The Great Horn of Africa (GHA) region is divided into three main sectors. The northern sector of the GHA covers Sudan, Ethiopia, Eritrea, Djibouti, and northern Somalia; the equatorial sector covers Uganda, Kenya, Burundi, Rwanda, southern Somalia, and northern Tanzania; and the southern sector covers central and southern Tanzania. December–February marks the main rainfall season over much of the southern sector, while March–May marks the main rainfall season (known as the long rainfall season) over the equatorial sector. A secondary rainfall season (known as the short rainfall season) over the equatorial sector is usually observed from late September to early December. The northern sector mainly receives rainfall from June to early September.

*(i) Temperature*

Warmer-than-average minimum and maximum temperature anomalies were observed over most parts of the GHA throughout 2010. February was exceptionally warm, with minimum temperature anomalies greater than +2°C recorded over much of Sudan, central and western Ethiopia, Kenya, Rwanda, northern Burundi, and southern Uganda (Fig. 7.21).

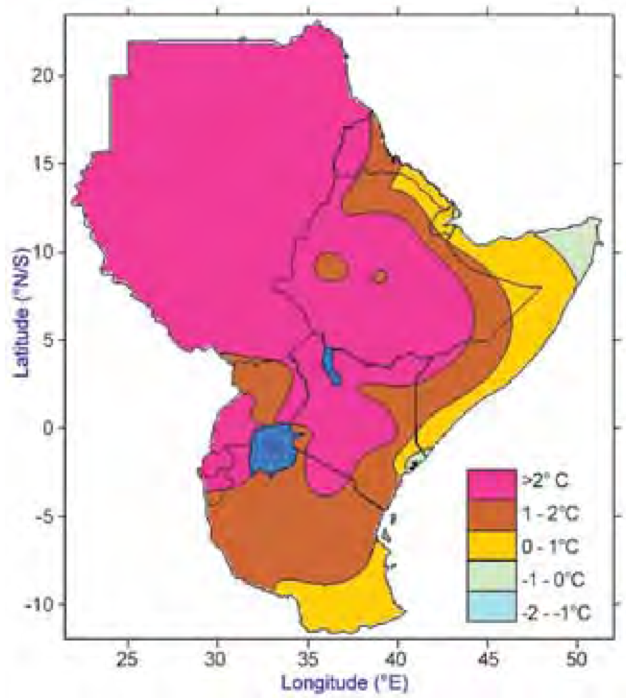


**Fig. 7.21. February 2010 minimum temperature anomalies for the Great Horn of Africa (based on 1961–90 base period). (Source: ICPAC.)**

*(ii) Precipitation*

From December 2009 to February 2010, much of Somalia, Ethiopia, Kenya, northern Uganda, and southern Sudan received more than 175% of their long-term average (1961–90). Southern and western parts of Kenya, southern Uganda, Tanzania, Rwanda, and localized parts in Sudan, Djibouti, and Ethiopia received between 125% and 175% of their long-term average. However, it was drier than normal in the southern regions where less than 25% of average was observed in southern Tanzania, southern Eritrea, and parts of Ethiopia and Sudan.

Over the equatorial sector, most of the region received near-average rainfall from March to May, with anomalies between 75% and 175% of their long-term average (Fig. 7.22a). The western parts of the southern sector and northeastern parts of northern sector of the GHA received less than 75% of their long-term average.

June–August marks the main rainfall season over the northern sector and the coldest period over the equatorial sector. The western parts of the equatorial sector received substantive rainfall over this period. The northern and southeastern parts of the northern sector, southwestern and southern parts of equatorial sector as well as most of the southern sector received less than 75% of their long-term average. Much of the central and southern parts of the northern sector, and northwestern, central, and eastern parts of the equatorial sector received between 75% and 125% of their long-term average. Localized areas over northeastern Sudan, western Uganda, and central and eastern Kenya received more than 125% of their long-term average for the three-month period.

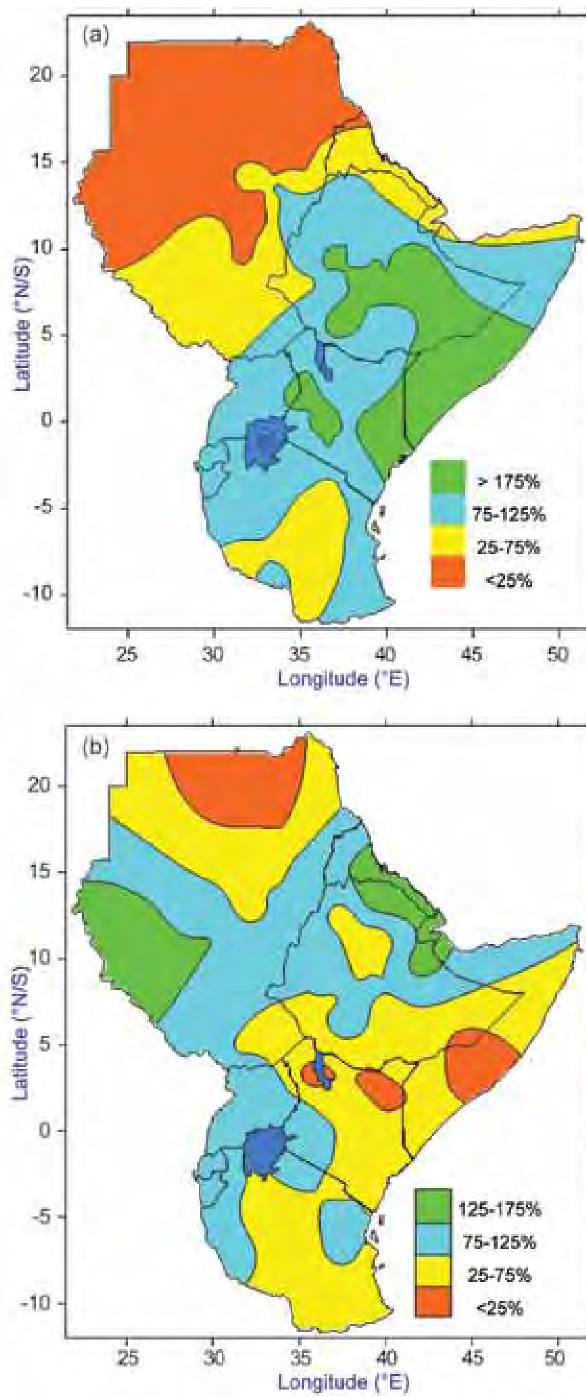


**Fig. 7.22. (a) March–May 2010 and (b) September–December 2010 rainfall anomalies (% of 1961–90 base period) for the Great Horn of Africa. (Source: ICPAC.)**

The second rainfall season for the equatorial sector is from September to December. Much of the eastern parts of the equatorial and southern sectors as well as the northern parts of the northern sector received less than 75% of their long-term average (Fig. 7.22b). The western parts of the equatorial and southern sector as well as central parts of the northern sector received between 75% and 125% of their long-term average rainfall for the period.

*(iii) Notable events*

The eastern equatorial sector recorded deficient rainfall, especially during the second rainfall season (September–December). Both direct and indirect impacts from the below-average rainfall resulted in cumulative climate stress on climate-dependent sectors. Such impacts observed in 2010 included loss of livestock due to inadequate pastures, food insecurity from crop failure, rationing of hydropower and limited water for domestic and industrial uses from scarcity of the water resources, water contamination, and poor health from malnutrition.

4) Southern Africa—A. Kruger, C. McBride, and W. M. Thiaw

This region includes the countries south of 15°S, with a focus on South Africa.

*(i) Temperature*

The year 2010 was a warm year for Southern Africa, where the annual mean temperature was above average. For South Africa, annual mean temperature anomalies, based on preliminary data from 27 climate stations, were about 0.8°C above the reference period (1961–90); this makes 2010 the second warmest year for the region since 1961 (Fig. 7.23).

*(ii) Precipitation*

In South Africa, January–March was characterized by above-normal rainfall over the central and western interior, but drier than normal elsewhere. During April–June, the northern interior received above-normal rainfall, while it was drier in the western interior. For July–September, very dry conditions were experienced over most of the country, including regions in the southwest where the bulk of its annual rainfall is received during this time of the year. October–December shows normal to above-normal rainfall over most of the country. In December, some summer rainfall regions received rainfall well above average, with flooding in many areas. The annual rainfall anomalies indicate that regions primarily in the coastal provinces were dry in 2010 (Fig. 7.24).

For Southern Africa, rainfall totals from November 2009 to April 2010 ranged between less than 100 mm along West Coast South Africa and coastal Namibia to over 1200 mm along the border between northern Zambia and the Democratic Republic of Congo, and along northern and east coast Madagascar (Fig. 7.25a). Southern Africa austral summer features two basic climate zones. The southwestern sector is much drier on average than the remainder of region. The area of maximum precipitation in the northern part of the region registered rainfall amounts between 700 mm and 1200 mm. To the south, rainfall in the crop areas of eastern Botswana, Zimbabwe, central Mozambique, and northeastern South Africa received 300 mm–800 mm, while the climatologically dry zone recorded less than 100

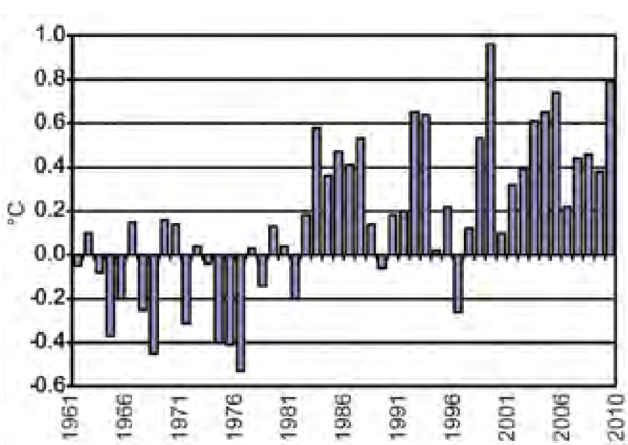


**Fig. 7.23. Annual mean temperature anomalies in South Africa (average of 27 stations) for the period 1961–2010 (based on 1961–90 base period). (Source: South African Weather Service.)**

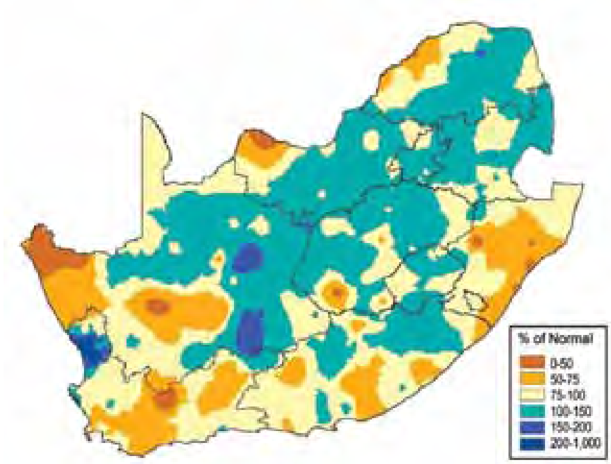


**Fig. 7.24. 2010 rainfall anomalies (% of 1961–90 base period) for South Africa. (Source: South African Weather Service.)**

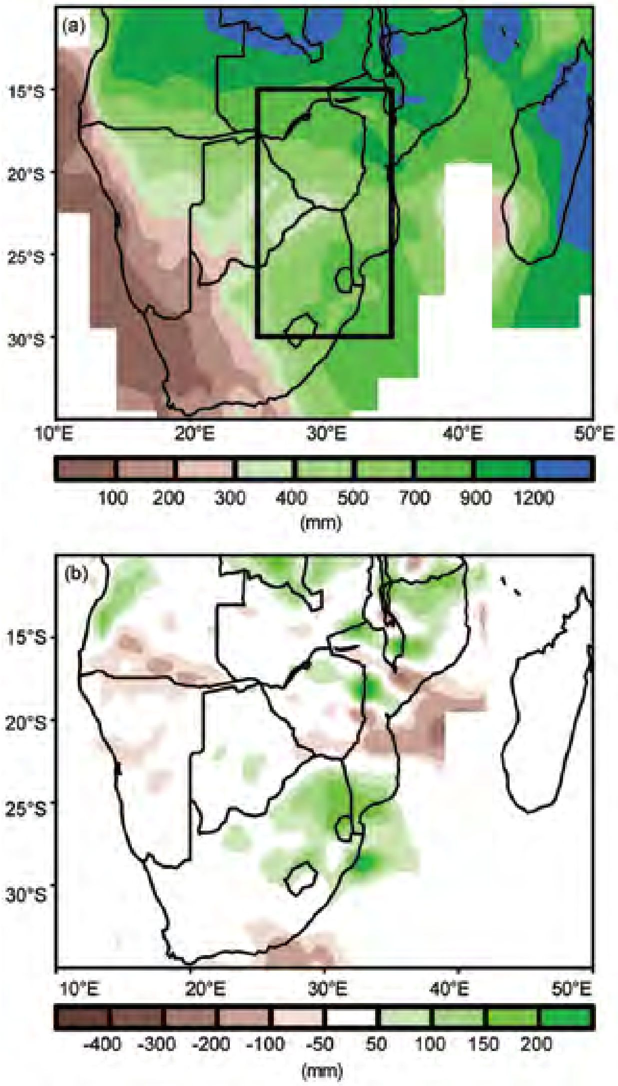


**Fig. 7.25. November 2009–April 2010 (a) rainfall (mm) for Southern Africa and (b) rainfall anomalies (% of 1971–2000 base period). (Source: NOAA/NCEP.)**

mm–300 mm. Overall, the rainfall season did not exhibit significant departures from climatology during the 2009/10 season (Fig. 7.25b). Rainfall was near average across most areas in the central sector of Southern Africa. Areas of enhanced rainfall included the Maize Triangle of northeastern South Africa and the northern areas of Mozambique, Zambia, and western Angola. Rainfall was below average over central Mozambique, southern Zimbabwe, and along the border between Angola and Namibia.

*(iii) Notable events*

In South Africa, heavy rains fell over Gauteng, Limpopo, and North West during January. A number of people drowned and many people had to be rescued from low-lying areas. Houses and informal settlements suffered damages, with many families temporarily housed in community halls. The Vaal Dam was over 100% full for the first time in 13 years and the sluice gates had to be opened, causing flooding downstream of the dam. Bloemhof Dam and the Wolwespruit Nature Reserve in North West were closed due to flooding of the Vaal River. Towards the end of January, heavy rain caused damage in the eastern province of KwaZulu-Natal.

Snow was reported on the mountains of Western and Eastern Cape on 14 and 15 June, resulting in several road closures. Snow also fell as far as Murraysburg in the Karoo for the first time in 18 years. During this period, about 600 of 700 penguin chicks died on Bird Island, which is part of the Addo Elephant Park near Port Elizabeth in the Eastern Cape.

KwaZulu-Natal experienced very hot conditions on 14 September, which negatively affected many people, especially the elderly and children. Some stations, especially along the coastal regions, reported maximum temperatures above 38°C, some of which were new record maximum temperatures.

Severe hailstorms damaged houses and cars and killed livestock in Limpopo on 24 October. The most affected areas were Tzaneen, Tubatse (Burgersfort), and Polokwane. A severe hail and rainstorm also hit Levubu district, resulting in the loss of as much as 30% of banana crop. According to reports, it was the worst hailstorm in 15 years and some of the hailstones were the size of golf balls.

Veld fires ignited by lighting and fanned by strong winds burned at least 88 000 hectares of grazing pastures in Limpopo at the beginning of October. The fires destroyed an area covering about 170 km$^2$ in the Waterberg area. More than 250 people, including teams from the Working on Fire Programme, the police, emergency services, farmers, and farm workers, tried to get the fires under control. Lighting also ignited nine veld fires in the Soutpan, Free State, on 7 October. At least three people died and seven were seriously injured.

A tornado with large hailstones caused extensive damage in the towns of Dewetsdorp and Winburg in Free State on 27 December. On a farm in Kleinfontein near Dewetsdorp, parts of a large storeroom were destroyed while a caravan was picked up and dropped down about 60 meters away. Roofs were damaged and windows were broken. Electricity and telephone poles were also blown over. In and near Winburg, hail caused damage to buildings and cars.

In Broederstroom, North West province, on 16 December, more than 100 mm of rain fell within 30 minutes. At least four families living along the Crocodile River were cut off from the outside world after the river burst its banks. Three houses were flooded. Heavy rain also fell in Pretoria, causing damage to infrastructure. The worst affected areas were in Centurion and north of Pretoria where a bridge on the Klipgat Road near Mabopane was destroyed. The flooding also affected parts of the Centurion Lake Hotel, damaging several cars. A low water bridge at the Apies River in Capital Park was closed after flood waters caused some structural damage to the bridge. In Mabopane, a man was rescued after he was trapped in raging water for nearly five hours when he tried to cross a small spruit (stream that flows only during the wet season) near Morula Sun.

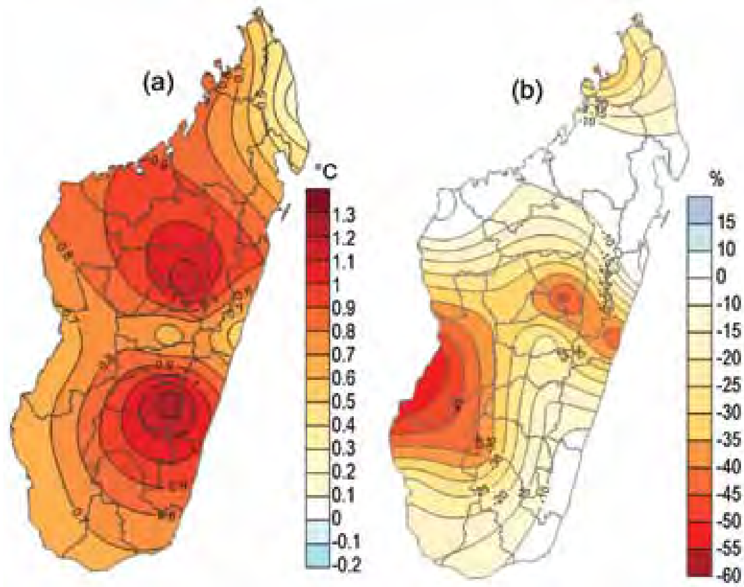


**Fig. 7.26. 2010 (a) annual mean temperature anomalies (based on 1971–2000 base period) and (b) annual precipitation anomalies (% of 1971–2000 base period) in Madagascar. (Source: Service Météorologique de Madagascar).**

5) Western Indian Ocean Countries—R. Faniriantsoa, S. Andrianiafinirina, G. Jumaux, D. Schueller, P. Booneeady, and V. Amelie

This region is made of many islands grouped into five countries, namely Madagascar, Reunion (France), Mauritius, Comoros, and Seychelles.

*(i) Temperature*

For Madagascar, the annual mean temperature was 0.4°C–1.3°C above the 1971–2000 average across the country (Fig. 7.26a). The highest annual temperature anomalies were observed at Fianarantsoa (+1.3°C) and Ivato (+1.2°C). February, April, May, June, and October were generally well above average across the entire country. The highest monthly anomaly was observed in Ranohira (+2.1°C) in April and in Mrorondava (+2.0°C) and Nosy-Be (+2.2°C) in June. Some negative anomalies were found in Taolagnaro in January (-0.6°C), Morondava in September (-0.5°C), and Sambava in November (-0.6°C).

For Reunion, 2010 was the warmest year on record since 1971 (Fig. 7.27), with an annual mean temperature anomaly of +1.05°C (+0.87°C and +1.23°C for annual minimum and maximum temperature, respectively). The year 2009 is the second warmest year on record, and 9 of the 10 warmest years occurred during the 2001–10 decade. The year 2010 had the warmest May, June, and October recorded since 1971. On Tromelin Island, 2010 was the warmest year on record, with an annual temperature anomaly of +0.96°C. At Mayotte (Pamandzi Airport), 2010 was slightly warmer than 1998, with an annual temperature anomaly of +1.06°C.

The year 2010 was also the warmest year on record in Mauritius during the decade 2001–10. The annual mean temperature was above the 1971–2000 average by around 1.2°C for Mauritius, 1.1°C for Rodrigues, 1.0°C for St. Brandon, and 0.7°C for Agalega.

For Seychelles, the annual mean temperature for 2010 was 0.6°C above average. Except for November, with a departure of -0.2°C from average, all months recorded monthly mean temperatures above average (Fig. 7.28). Seychelles also observed an annual warm anomaly of +0.5°C and +0.7°C in maximum and minimum temperatures, respectively.

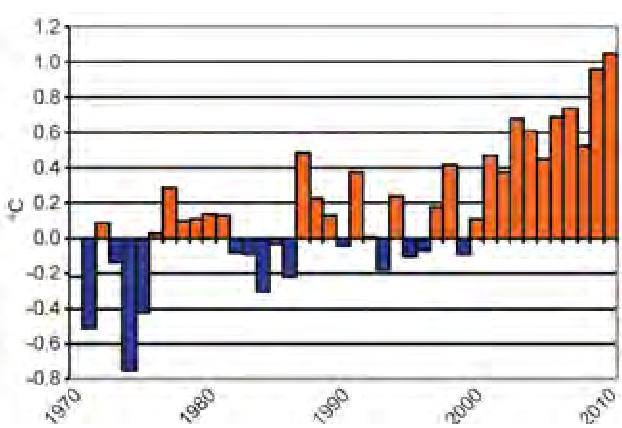


**Fig. 7.27. Annual mean temperature anomalies for Reunion (average of 10 stations), for the period 1970–2010. (Source: Météo-France.)**

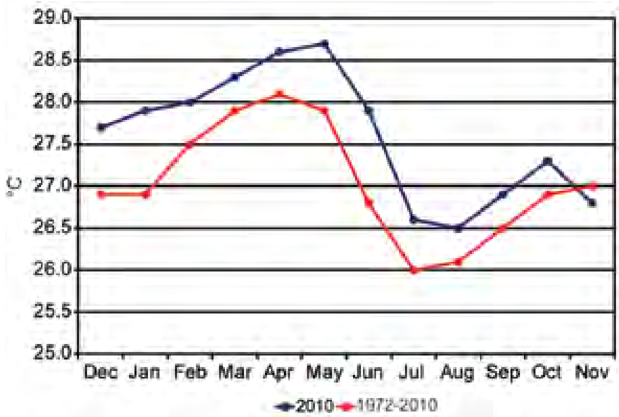


**Fig. 7.28. December 2009–November 2010 monthly mean temperatures and 1972–2010 monthly averages for Seychelles International Airport. (Source: Seychelles Meteorological Services.) )**

*(ii) Precipitation*

Annual accumulated precipitation was generally below average across Madagascar (Fig. 7.26b) with a few exceptions; Antsohihy, Taolagnaro, Besalampy, Toamasina, Sainte Marie, and Farafangana were all near average. Monthly rainfall was generally below average during the rainy season. March and May were the exceptions, with monthly rainfall above average for a few stations; in March, total rainfall was 836.6 mm for Farafangana (150% of normal), 363 mm for Fianarantsoa (170%), and 490.4 mm for Taolagnaro (217%); and in May, total rainfall was 35.7 mm for Morombe (208%) and 86.6 mm for Toliara (587%). These strong anomalies were due to the passage of Tropical Cyclones Hubert (9–11 March) and Joel (25–29 May).

For Reunion, the average precipitation anomaly was -6% (17th driest year since 1971), with values ranging from -30% to +30% from the west to high elevations of the southeast. October–December was the second driest such period on record, behind 1992. Annual negative precipitation anomalies were also registered in Tromelin (-12%) and Pamandzi Airport (-15%).

In Mauritius, total rainfall recorded in 2010 was slightly below average in Plaisance and Vacoas while it was near normal at Rodrigues, St. Brandon, and Agalega. December 2010 rainfall was the lowest ever recorded in the main island—15 mm—amounting to 8% of the 1971–2000 long-term average.

*(iii) Notable events*

In Seychelles, the rainy season started late and November 2010 had the lowest recorded November rainfall, at 85% below average. Rainfall deficit continued in December, a month which normally receives enough rain to fill the country's main dam. But at the end of the month, the dam was only 50% of full capacity, forcing the government to impose strict restriction on water supply; many households and business establishments received only a few hours of this essential commodity per day.

*f. Europe*—F. Maier, A. Obregon, P. Bissolli, J. J. Kennedy, D. E. Parker, R. M. Trigo, D. Barriopedro, C. M. Gouveia, S. Sensoy, and C. Achberger

1) Overview—F. Maier, A. Obregon, P. Bissolli, R. M. Trigo, J. J. Kennedy, and D. E. Parker,

Europe was on average warmer than normal in 2010, but cooler than in recent years (Fig. 7.29), and some parts were even colder than normal (Fig. 7.30). The mean land surface air temperature for the European region (35°–75°N, 10°W–30°E) from the CRUTEM3 dataset (Brohan et al. 2006) was 0.24 ± 0.13°C above the 1961–90 normal. According to interpolated CLIMAT and ship observations, only

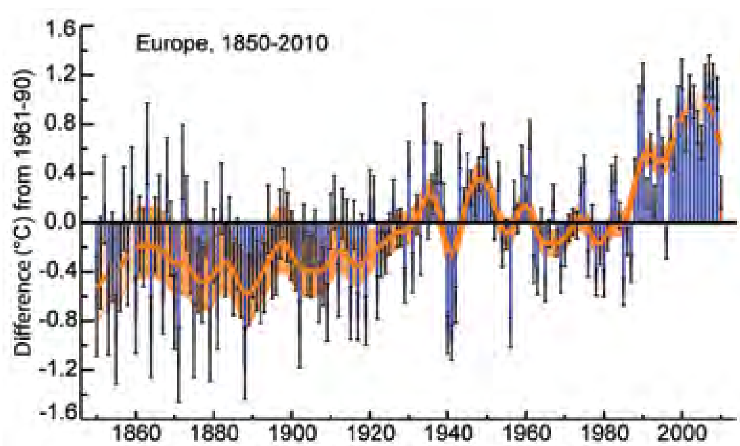


**Fig. 7.29. Annual average land surface air temperature anomaly for Europe (35°N–75°N, 10°W–30°E). The blue bars show the annual average values and the black error bars indicate the 95% confidence range of the uncertainties. The red bar is the annual value for 2010. The smooth orange line shows the annual values after smoothing with a 21-point binomial filter. The dashed portion of the line indicates where the smoothed curve is affected by the choice of end-point padding and is liable to change in future. The hatched orange area indicates the 95% confidence range on the smoothed values. Data are from the CRUTEM3 dataset (Brohan et al. 2006).**

a few areas were significantly warmer than average (Fig. 7.30). Temperatures were especially high across Greenland with a maximum positive anomaly[1] of more than +4°C, and in parts of Eastern Europe and the Middle East with +3°C. In contrast, much of Northern, Western, and Central Europe had below-average temperatures in 2010. It was the coldest year since 1996 in several countries in Western and Northern Europe, mainly due to well-below-normal temperatures during winter 2009/10, autumn, and December 2010. Western and Central Europe experienced their most severe winter season (DJF 2009/10)[2] for at least 14 years (Fig. 7.31, DJF). In contrast, Greenland, Svalbard, and large parts of southeastern Europe and the Middle East had much warmer-than-usual winter temperatures, with anomalies surpassing +4°C.

The mean European spring (MAM, 2010) temperatures were above normal across the region, with some local exceptions in Central and Northern Europe (Fig. 7.31, MAM).

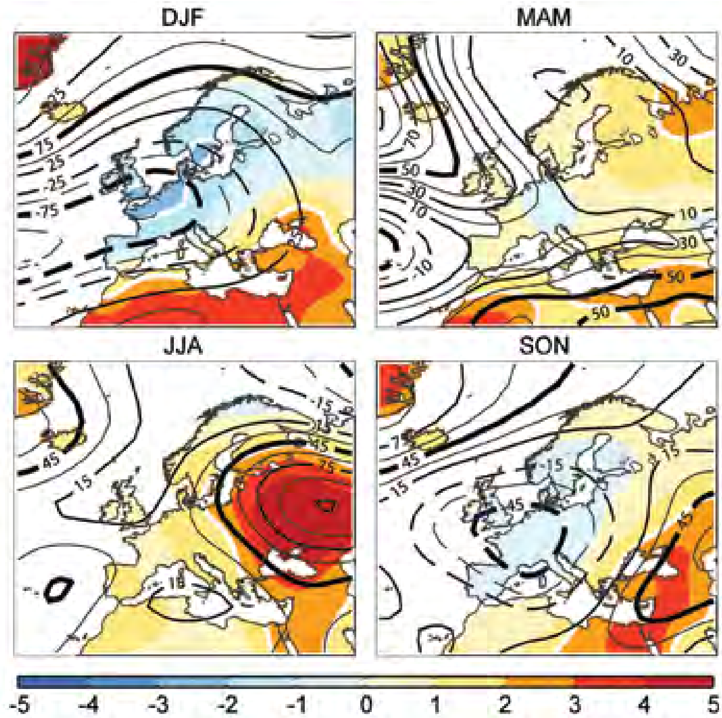


**Fig. 7.31. Seasonal anomalies (relative to 1961–90 base period) of 500-hPa geopotential height (contour, gpm) and 850-hPa temperature (shading, °C) using data from the NCEP/NCAR reanalysis (Kalnay et al. 1996). Winter (DJF), spring, (MAM), summer (JJA), and autumn (SON). Black (white) thick lines highlight those geopotential height (temperature) contours with all the encircled grid points having absolute anomalies outside the ± 1 standard deviation range of the base period.**

[1] The standard reference period used in this section for European averages is 1961–90 for temperature and precipitation, unless otherwise specified.

[2] All seasons mentioned in this section refer to the Northern Hemisphere (months given in brackets).

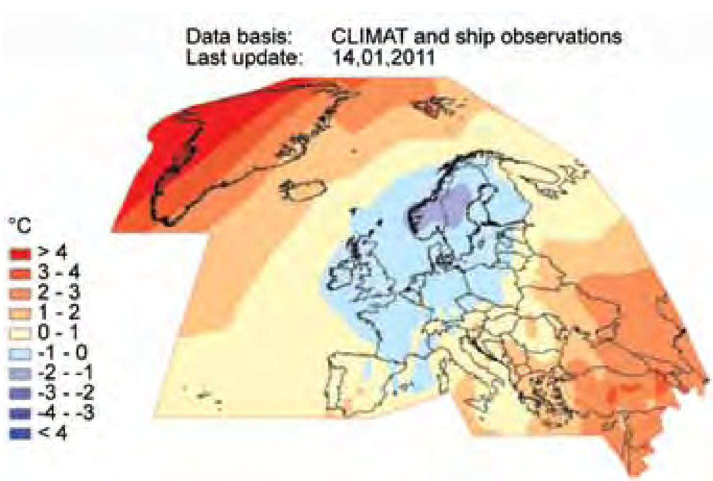


**Fig. 7.30. Annual mean temperature anomalies for 2010 in Europe and over the North Atlantic (°C, 1961–90 base period) based on CLIMAT and ship observations. (Source: Deutscher Wetterdienst.)**

During summer (JJA, 2010), a persistent omega block over European Russia caused an exceptionally extensive heat wave that affected Eastern Europe. The blocking lasted for more than one month and new records of daily maximum temperature and minimum monthly precipitation were set in many locations in Eastern Europe and Finland. Only a few northernmost European areas had below-average temperatures in summer (Fig. 7.31, JJA).

In autumn (SON, 2010), Greenland, the Middle East, and southeastern parts of Europe had local all-time records of positive seasonal temperature, with anomalies up to +3°C (Fig. 7.31, SON). September and October were colder than normal in most of continental Europe. The situation changed during November when temperatures became very mild for this time of year in Central and Eastern Europe. In the United

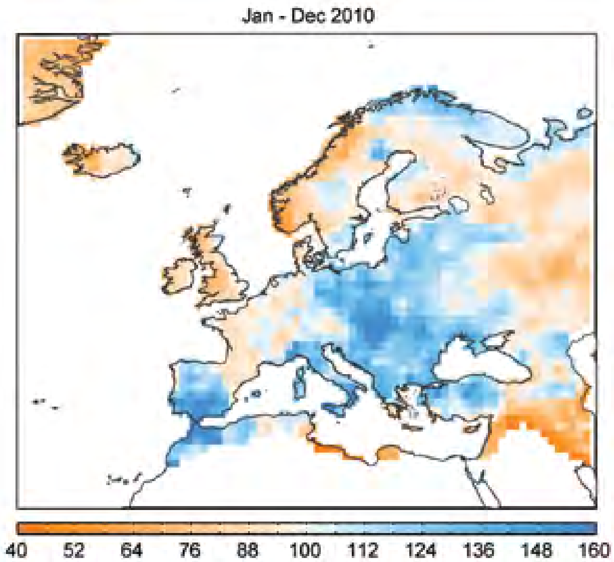


**Fig. 7.32. European precipitation totals (% of 1961–90 normal) for 2010. [Source: Global Precipitation Climatology Centre (GPCC), Schneider et al. 2008.]**

Kingdom, Ireland, and Spain, the conditions were reversed, with mild temperatures in September and lower-than-average temperatures towards the end of autumn.

The first three weeks of December brought severe winter weather to most of Europe, many parts being gripped by frigid Arctic air. Several minimum temperature records were broken. In contrast, the eastern Mediterranean countries experienced positive temperature anomalies.

Precipitation totals in 2010 were generally above average across much of the region, except northern and western parts of Europe, western Russia, and the Middle East (Fig. 7.32). Particularly, the Iberian Peninsula and most of the Mediterranean basin were characterized by significantly higher-than-usual annual averages (Fig. 7.32).

Northern, Western, and Central Europe experienced abundant snowfall in winter 2009/10, but mostly below-normal precipitation totals (Fig. 7.33, DJF). However, the rest of continental Europe showed mostly above-average seasonal precipitation. Spring precipitation anomalies were heterogeneous (Fig. 7.33, MAM). In May, heavy rainfall led to major flooding in eastern Central Europe. Very dry conditions were observed in the UK, France, and southern Scandinavia as well as in the Middle East.

September and November precipitation totals were higher than normal across Central and Western Europe (Fig. 7.33, SON). However, October had mostly negative anomalies in these areas. The Nordic countries experienced drier-than-usual conditions during autumn, with some parts down to 40% of normal.

December precipitation was generally higher than normal in Western, Central, and Eastern Europe and in most of Iberia, exceeding 300% of the long-term average in parts of southern Spain, but very low in Northern and northwestern Europe.

The European climate in 2010 was dominated by strong negative readings of the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO), enabling the frequent advection of Arctic air masses to the south while the Arctic regions were more influenced by warmer air masses (Cattiaux et al. 2010). The negative NAO was particularly relevant during the wet winter (DJFM) months, when it caused an attenuation of the westerlies from the North Atlantic, resulting in severe winter cold surges across Central Europe (yet milder than comparable spells in past decades because of the long-term warming trend, Cattiaux et al. 2010). However, the negative NAO-like phases dominated the entire year, giving moist conditions over the Mediterranean countries (Vicente-Serrano et al. 2011).

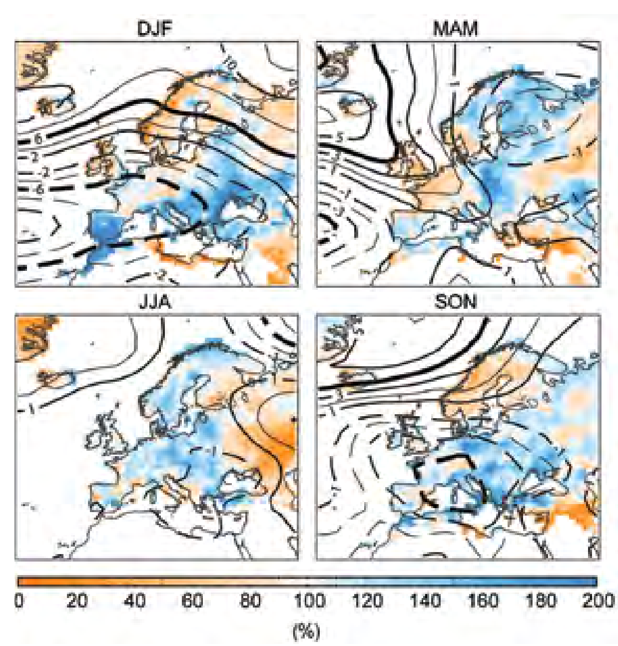


**Fig. 7.33. Seasonal anomalies of sea level pressure (hPa, relative to 1961–90 base period) from NCAR/NCEP reanalyses (contours). Colored shading represents the percentage of accumulated seasonal precipitation compared with the 1961–90 climatology from the seasonal GPCC precipitation dataset (only values above 15 mm per season are represented). Thick black lines highlight those sea level pressure anomalies which are more than one standard deviation from the mean.**

2) Central and Western Europe—F. Maier, A. Obregón, P. Bissolli, J. J. Kennedy, and D. E. Parker

Ireland, United Kingdom, the Netherlands, Belgium, Luxembourg, France, Germany, Switzerland, Austria, Poland, Czech Republic, Slovakia, and Hungary.

*(i) Temperature*

Most of Western and Central Europe had a cold year (Fig. 7.30). The UK averaged about 0.4°C below normal. Ireland experienced its coldest year since 1986. In France, 2010 tied with 1996 as the coldest year since 1987. In Germany, the 2010 mean temperature was below average for the first time after 13 consecutive warmer-than-normal years.

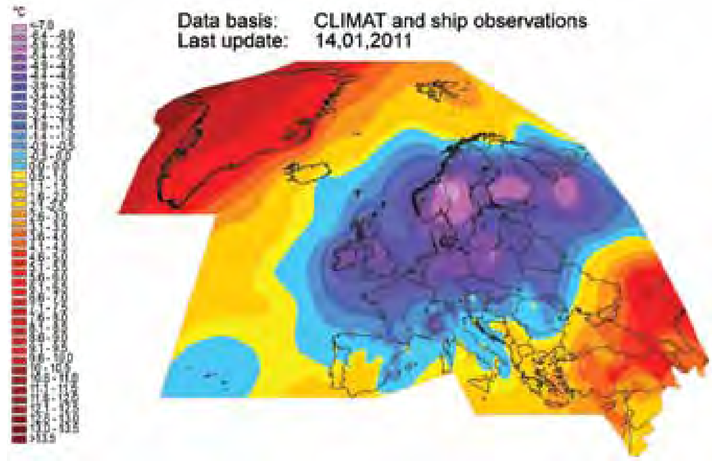


**Fig. 7.35. December 2010 mean temperature anomalies in Europe. (°C, 1961–90 base period) (Source: Deutscher Wetterdienst.)**

Winter was colder than normal over most of Western and Central Europe (Fig. 7.31, DJF). Many countries had their coldest winter for many years (see Sidebar 7.7).

In spring, a warm April contrasted with a mostly cool May, particularly in Central Europe. However, April 2010 was not as warm as the outstanding April months in 2007 and 2009, at least in France and Germany. The Netherlands experienced the coolest May since 1991.

Warmer-than-average summer temperatures were recorded throughout Western and Central Europe (Fig. 7.31, JJA). The UK monthly mean temperature anomaly decreased from +1.5°C in June to 0.0°C in August, the coldest August since 1993. July was particularly warm in Central Europe, at least +3°C warmer than normal in Germany, Poland, the Czech Republic, and Slovakia (Fig. 7.34).

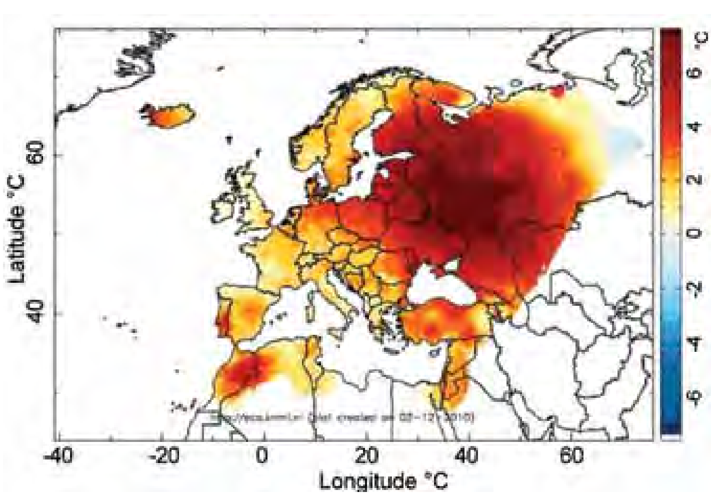


**Fig. 7.34. European temperature anomalies (°C relative to 1961–90 base period) during July and the first two weeks of August. (Source: ECA&D.)**

Most of Central Europe saw negative anomalies in September and October, from slightly below 0°C to below -2°C. November, conversely, was warmer than usual in Central Europe but had negative anomalies in Western Europe. The UK experienced a November temperature anomaly of -1.3°C, making it the coldest November since 1993. The last week of November was particularly cold everywhere in Western and Central Europe. In Switzerland, several locations set new records of minimum temperatures (e.g., La Brévine on 30 November with -31.4°C). In contrast, November was more than +3°C warmer than average in Hungary, and more than 4°C above normal in parts of Bosnia and Herzegovina.

December was extremely cold in Western and Central Europe (Fig. 7.35). The monthly temperatures were between -3°C and -5°C below normal in Germany and France, making it the coldest December for more than 40 years. In the UK, it was the coldest December for more than 100 years and the second coldest in the 352-year Central England Temperature series.

*(ii) Precipitation*

Western Europe experienced generally negative precipitation anomalies whereas Central Europe had near- or above-normal precipitation amounts (Fig. 7.32). Only 85% of the 1961–90 average fell in the UK in 2010. On the other hand, almost all parts of eastern Central Europe received more than 125% of normal rainfall.

Winter precipitation was much-below normal in most of Western and Central Europe, except southeastern parts (Fig. 7.33, DJF). In Ireland, Dublin Airport had its driest winter since 1963/64. January was particularly dry (80% of normal or less) over large areas of Western and parts of Central Europe. Nevertheless, winter 2009/10 was one of the snowiest in Western Europe (see Sidebar 7.7 for further details).

Spring precipitation totals were below average in Western Europe but above average in most of Central Europe, particularly in the east (Fig. 7.33, MAM). April was very dry over much of the region except the southeast. Germany reported its third driest April since 1901, but an unusually wet May. Over large areas from eastern Austria to Hungary, May 2010 was among the wettest ever registered. The UK experienced its driest spring season since 1984 as April and May were particularly dry with about 50% of the 1961–90 normal in England and Wales.

Summer rainfall was close to average in Western Europe, though with high temporal variability. June was very dry in Ireland, the UK, and most of Central Europe, whereas most of France, Slovakia, and Hungary were very wet. In July, large amounts of rain hit Ireland and most of the UK, but large parts of the French coasts were significantly dry. August was extremely wet all over Central Europe, whereas another dry spell prevailed over Ireland, western parts of the UK, and southwestern France. August was the wettest or second wettest in many parts of Central Europe for more than a century (e.g., the Netherlands, Germany, Slovakia), with around two to three times the monthly normal.

September and November precipitation totals were mostly above normal across Central Europe, exceeding the 90th percentile in Poland and eastern Germany in both months. These wet spells were interrupted by a mostly dry October, with some local exceptions. Poland, which had several flooding events in May, August, and September, experienced an extremely dry October, with less than 20% of the monthly normal rainfall in places. In the last week of November, widespread snowfall occurred over Western and Central Europe.

*(iii) Notable events*

On 27–28 February, the violent Atlantic cyclone Xynthia (969 hPa) tore along coastal Western Europe. It was the worst storm in the region since 1999, killing 62 people, mostly in France where sea walls broke in L'Agillon-sur-Mer, Vendée because of exceptional flooding. One million people were left without power across Portugal, Spain, France, Belgium, Netherlands, Germany, and southeast England after wind speeds reached nearly 160 km $hr^{-1}$.

On 9 August, violent floods hit eastern Central Europe, killing 11 people and damaging hundreds of houses. The Neisse River on the Polish-German border rose to 4.5 m above normal and more than 1400 residents had to leave their homes.

Severe winter weather affected Western and Central Europe during the first three weeks of December 2010 due to advection of cold arctic air (Fig. 7.35) associated with a strongly negative Arctic Oscillation. Most of the United Kingdom had snow during at least half of the month (Fig. 7.36). Airports were forced to close in Switzerland, Germany, France, Belgium, and the Netherlands. The Italian Isle of Capri experienced its first snow in 25 years on 3 December. On 28 December, the lowest temperature ever recorded in Northern Ireland was measured with -18°C at Castlederg.

3) The Nordic and Baltic Countries—F. Maier, A. Obregón, P. Bissolli, and C. Achberger

Iceland, Norway, Denmark, Sweden, Finland, Estonia, Latvia, and Lithuania.

*(i) Temperature*

The year 2010 was the coldest year since 1996 in most parts of Northern Europe, mainly due to well-

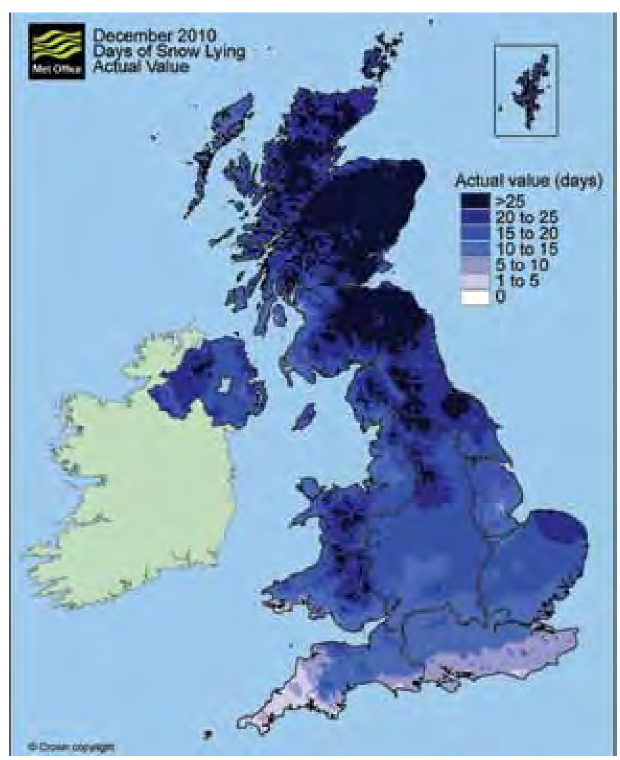


**Fig. 7.36. Number of days of snow lying in December 2010 for the UK. (Source: UK Met Office.)**

below-average temperatures during winter 2009/10 and December 2010. Norway reported an anomaly of -1.0°C, the 10th lowest value since 1900. In stark contrast, Iceland and Greenland experienced positive anomalies exceeding up to +4.0°C (Fig. 7.30).

All regions of Northern Europe had negative anomalies in winter, except Greenland and Svalbard, which had temperature anomalies exceeding +4°C (Fig. 7.31, DJF). The Norwegian winter was the 11th coldest on record, -2.5°C below average.

Spring temperatures were above normal across Northern Europe (Fig. 7.31, MAM). Only a few regions in Norway were colder due to a cold March and May in some areas. April, however, was mild in Northern Europe as a whole, except Iceland. Highest positive anomalies in April were reported in western Greenland (> +4°C). In northern parts of Sweden, unusually high temperatures, combined with heavy rain, caused locally severe mudslides in late spring.

Except areas in the far north, all regions experienced positive summer anomalies with maxima over Greenland and the Baltic countries exceeding +2°C (Fig. 7.31, JJA). While June was colder than normal across Fennoscandia, both July and August were warmer than normal. July was around +3°C above normal in Denmark, Sweden, and Finland. During July, the 500-hPa circulation featured a strong and persistent ridge over Fennoscandia, leading to exceptionally warm and dry conditions. A couple of stations in southern Sweden reported new all-time high temperatures since measurements began in the mid-19th century. Finland reported an extremely warm July in the country, breaking many local records. For example, a new all-time temperature record of 37.2°C was set on 29 July at Joensuu Airport, Liperi, beating the former record set in Turku in 1914 by +1.3°C. Also, Latvia and Lithuania reported the hottest July since the beginning of meteorological observations with country average temperatures of 21.5°C (+4.8°C anomaly) and 22.2°C (+5.4°C), respectively.

Only Iceland, Svalbard, and Greenland experienced positive anomalies in autumn, while several regions of Northern Europe were colder than average (Fig. 7.31, SON). Denmark had its coldest autumn since 1998 when mean temperatures around 8°C prevailed. Norway's average autumn temperature was 1.1°C below normal, which was also the most extreme negative seasonal anomaly in Northern Europe. Lithuania was unusually warm during November with daily maxima up to 15°C in many places, exceeding all previous records for November.

The winter season 2010/11 of Northern Europe started with enormous negative anomalies, except for Iceland and the Arctic. With nationwide average temperatures of -6.6°C for December, Latvia experienced its fourth coldest month in the last 67 years. Norwegian average temperatures for December were the fourth coldest ever recorded (4.7°C below normal).

*(ii) Precipitation*

Total annual precipitation was generally normal or slightly below normal over the Nordic countries and the Baltic region. Iceland had the lowest number of days with snow cover since 1921.

The lack of normal westerly flow during winter 2009/10 resulted mostly in dry conditions in Northern Europe (Fig. 7.33, DJF), with western Norway having its driest winter on record (28% of normal). Norway as a whole had around half of its normal seasonal precipitation totals and its second driest winter on record, surpassed only by winter 1899/1900. January was generally dry over almost all of northern continental Europe, with precipitation totals as low as 40% of normal in some regions.

Spring precipitation was mostly above normal in Northern Europe (Fig. 7.33, MAM), locally up to twice the normal in northern Norway. Only Svalbard, parts of Greenland and Iceland, southern parts of Norway and Sweden, and most of Denmark saw a dry spring; in southern Norway totals were less than 50% of normal.

Summer precipitation totals were between 125% and 150% of normal in large parts of the Nordic and Baltic countries with a few exceptions, namely Greenland, Svalbard, Iceland, and southern Finland (Fig. 7.33, JJA). Summer 2010 was the third wettest in Latvia since meteorological measurements began.

Autumn precipitation in Denmark and the Baltic countries was slightly above average. In contrast, most of Fennoscandia and Iceland experienced a rainfall deficit down to 40% of normal (Fig. 7.33, SON). A snow depth of 85 cm occurred locally in southern Sweden in November, which was a new record.

*(iii) Notable Events*

During April and May, upper level winds advected ash over the UK and continental Europe due to the Eyjafjallajokull volcanic eruption in Iceland. Although the eruption seldom rose above the tropopause, it caused the largest disruption of air traffic since World War II (Petersen 2010). As a consequence of the eruption, the glacier surrounding of the volcanic crater melted and caused flash floods that destroyed the infrastructure of the region. Almost 800 people had to leave their homes, but no fatalities were reported.

In northwest Greenland, a huge chunk of ice broke off the Petermann Glacier into the Nares Strait on 5 August. The ice floe was 251 $km^2$ in size, meaning a quarter of the floating ice shelf of the Petermann Glacier. It was the largest breakup in the Arctic since 1962 (see also section 5f7).

4) Iberia—R. M., Trigo, D. Barriopedro, C. M. Gouveia, F. Maier, A. Obregón, and P. Bissolli

Portugal and Spain.

*(i) Temperature*

Annual mean temperatures in Iberia were above the 1961–90 average throughout most of the region, though anomalies were mostly below +1°C (Fig. 7.30), and in Portugal only +0.24°C. Nevertheless, 2010 was the second coolest year since 1997 in Spain. Winter 2009/10 was slightly cooler than normal on most of the Iberian Peninsula, although not as cold as the rest of most of Western and Northern Europe (Fig. 7.31, DJF). The average temperature over Spain was 0.3°C below its normal value. The coldest month in Spain was February, with a mean temperature anomaly of -0.6°C.

Spring temperatures were slightly warmer than normal in most of the Iberian Peninsula (Fig. 7.31, MAM), +0.6°C averaged over Spain. However, spring 2010 was the second coolest since 1996. It was the coldest March in Portugal in the last 24 years. In contrast, April and May were warmer than normal, particularly in western and southern Iberia.

Although June temperature was near normal or slightly above normal, with a Spanish mean of +0.4°C above the 1971–2000 average, it was the coolest June since 1997. In contrast, July and August were exceptionally warm particularly over Portugal and eastern Spain. For July and August, the mean temperature anomaly averaged over Spain was +2.1°C and +1.3°C, respectively. The most significant hot spell occurred from 25 to 27 August. During this event, the 2010 highest maximum temperature of 43.0°C was recorded on the eastern coast of Spain. At many meteorological stations in eastern Spain (e.g., Murcia, Valencia), maximum August temperatures exceeded the historical records for this month. Similarly, maximum temperatures observed for Portugal in July (August) were the highest (second highest) since 1931. Generally, the temperatures during the rest of the year oscillated around their normal values on the Iberian Peninsula, with monthly mean anomalies mostly within ±1°C (Fig. 7.31).

*(ii) Precipitation*

Annual precipitation was above the 1961–90 average in most parts of the Iberian Peninsula, most notably in southern Spain, where the annual precipitation rate exceeded the average by more than 50% (Fig. 7.32). Portugal as a whole had its rainiest year of the last decade (2001–10), with total precipitation of 1063 mm, which is 120% of normal.

Winter 2009/10 precipitation over the Iberian Peninsula doubled its normal value (Fig 7.33, DJF). Because of the persistence of Atlantic air masses bringing abundant precipitation to the southwestern part of the Peninsula, the winter in Spain became the third wettest since 1947. Winter precipitation totals in large areas of southern Iberia and Madeira Island were the most extreme on record. According to Vicente-Serrano et al. (2011), more than 70% of 45 Iberian stations recorded monthly values higher than the 70th percentile (some higher than the 98th percentile) of the corresponding distribution in the winter months (DJF 2009/10); during March that threshold was surpassed by "only" 44% of stations. Lisbon received 958.6 mm of precipitation from December 2009 to March 2010, an all-time record since the beginning of regular measurements in 1865. The Iberian Peninsula experienced near-normal precipitation in spring with a slight north-to-south gradient (Fig 7.33, MAM). Local areas in Northern Iberia received less than 80% of the climatological average whereas the southern parts received up to 125%.

After a relatively wet June, July and August were mostly drier than normal. In particular, July was anomalously dry, with the highest negative anomalies of all months in 2010. Average July precipitation over Spain was around 50% of average, which is generally very low in summer months (less than 20 mm $month^{-1}$ over most of southern Iberia).

Considering the Iberian Peninsula as a whole, average autumn precipitation was near normal (Fig. 7.33, SON). The season was wet in northern Spain whereas the Spanish Mediterranean regions were drier than normal.

December 2010 precipitation on the Iberian Peninsula was among the highest in Europe, consistent with the tendency for above-normal precipitation in this region during negative NAO periods, such as in December 2010. The average cumulative rainfall for December over the Spanish territory was 160%

of normal. Only small parts of northeastern Spain registered below-average precipitation values.

*(iii) Notable Events*

On 20 February 2010, the island of Madeira was hit by torrential rainfall, with several stations above the capital city of Funchal registering more than 350 mm in 24 hours. The extreme event triggered catastrophic flash floods in three streams that crossed Funchal, leading to 45 deaths. Above-average winter precipitation in the previous months led to a saturation of moisture in soil, favoring increased surface runoff and these flash floods. This event was the deadliest hydrometeorological catastrophe in the Portuguese territory in the last four decades and economic damages were estimated at $ 1.9 billion (U.S. dollars).

Following the unusual rainy winter (DJF) season of 2009/10, large areas of the south and southwest of Iberia were affected by floods, particularly along the Guadalquivir River, with important socioeconomic impacts on agriculture, road and rail traffic, buildings, and infrastructure. Floods were directly responsible for nine fatalities and for displacing about 1000 people (Vicente-Serrano et al. 2011).

Torrential precipitation occurred in some locations of Andalucía on 16 August, in the middle of the dry season, causing three deaths and damage to infrastructure, mainly houses and transport networks (road and rail). Daily rainfall amounts of over 200 mm were measured in some places such as in Aguilar de la Frontera, Córdoba, where this amount accumulated in just a few hours.

5) Mediterranean, Italian and Balkan Peninsulas—F. Maier, A. Obregón, P. Bissolli, J. J. Kennedy, D.E. Parker, and S. Sensoy

Italy, Malta, Slovenia, Croatia, Serbia, Montenegro, Bosnia and Herzegovina, Albania, Macedonia, Greece, Bulgaria, and Turkey. Detailed summaries for Turkey, Iran, and Iraq may be found in section 7g4.

*(i) Temperature*

Mean annual temperatures in southeastern Europe were above the 1961–90 average, with annual temperature anomalies increasing from +0.2°C in northern Italy to more than +3.0°C in Turkey, which experienced its warmest year on record since 1940 (Fig. 7.30).

Winter 2009/10 temperature anomalies were high in the eastern parts of the region, exceeding +4°C in Turkey (Fig. 7.31, DJF). In Greece, New Year's Day was recorded as the warmest January day in 50 years. In Italy, a cold outbreak of Arctic air during the "giorni della merla" ("days of the blackbird", 29–31 January) brought widespread snowfall over northern Italy and were the coldest days of the year.

Anomalous warmth was widespread in the Mediterranean region in spring and particularly in summer with seasonal anomalies up to +2°C. Cold air outbreaks occurred only occasionally (e.g., in northern and central Italy associated with a strong cutoff low at the end of June). The highest monthly anomalies were recorded in August, when Macedonia and Greece reported their highest temperatures of the year.

Autumn was also warm in southeastern Europe (up to +3.0°C warmer than normal in the east), while Italy had near-normal temperatures (Fig. 7.31, SON). September and October were cold in Italy and most of the Balkan Peninsula (e.g., -3.5°C October anomalies in Serbia), followed by a very mild November (anomalies > +4°C) in large parts of southeastern Europe.

December showed strong contrasts within the Mediterranean region. Below-average temperatures were recorded in Italy, Slovenia, and Croatia, with anomalies locally below -2°C, while positive anomalies were observed in Greece, Macedonia, and Turkey up to over +4°C.

*(ii) Precipitation*

The year 2010 brought well-above-average precipitation over most of the Balkan Peninsula and over some parts of the Mediterranean region. Precipitation totals exceeded 125% of normal in some areas.

Above-average precipitation occurred in almost all parts of the southern region in winter 2009/10 (Fig. 7.33, DJF). Much of the precipitation fell as snow. Heavy rainfall affected southeastern Europe, particularly in February. The highest daily precipitation total in Serbia of 39.1 mm was measured on 25 February in Belgrade, exceeding the previous local February maximum recorded (3 February 1962) by 4.3 mm.

Spring was wetter than normal over the Italian and northern Balkan Peninsulas. Other parts of the region experienced drier-than-average conditions (Fig. 7.33, MAM). In March, there were still snowfalls in northern Italy, on the Ionian coasts, and in northern and central Greece, but heavy rain in Sicily. There were heavy thunderstorms in many parts of the region during April and May. The precipitation record for May was broken in Kikinda, Serbia, with a total of 202.6 mm.

In summer, Southern Europe was mostly very wet in June, but became very dry in August, except in its northern parts. Italy was hit by thunderstorms in August, particularly over its central and northern areas.

Wetter-than-average conditions prevailed during autumn in Southern and southeastern Europe (Fig. 7.33, SON). In Slovenia, estimated average rainfall total across the country during a 48-hr period in mid-September amounted to 170 mm–180 mm, making it the most severe precipitation event in the last 60 years (and exceeding the 100-year average return interval value) at several Slovenian stations. In October, Serbia monthly precipitation totals reached 300% of normal. A Mediterranean mesocyclone, originating from a cutoff low, affected the western Mediterranean basin during the second week of October. In contrast, eastern parts of the Mediterranean region experienced far-below-average precipitation in November.

December precipitation was generally above normal in northern Italy, most of Turkey, and the northern Balkan Peninsula, and well below average (less than 60%) in parts of central and southern Italy and Greece. Extremely heavy precipitation occurred in eastern and southern Bosnia and Herzegovina on 2 December.

*(iii) Notable Events*

On 12 February, Rome and the coasts of the central Tyrrhenian Sea were covered with snow, an unusual occurrence.

During the third week in June, heavy rains in Bosnia led to more than 30 landslides and caused river floods, forcing thousands of homes to be evacuated. Many Bosnians feared that land mines that had been planted during the Bosnian War in the 1990s were shifted by the floods.

In northwest Bosnia and Herzegovina (Bosanska Krupa) on 4 August, severe thunderstorms occurred, with very strong winds and hail up to the size of tennis balls. There were huge losses of infrastructure and agricultural production.

On 13-14 October, 123 mm of rainfall was recorded during a 24-hour period in Bursa, Turkey. This amount of rain in 24 hours is estimated to have an average return interval of 200 years.

6) Eastern Europe—F. Maier, A. Obregón, P. Bissolli, and J. J. Kennedy

European Russia, Belarus, Ukraine, Moldova, and Romania.

*(i) Temperature*

Eastern Europe was warmer than average during 2010 (Fig. 7.30). Anomalies were highest in the east and south and lowest in the west and north, ranging from +2.0°C to +0.2°C.

The winter season was colder than average in northern European Russia, but warmer in the other parts of Eastern Europe (Fig. 7.31, DJF). During a cold spell on 24–28 January, new records for lowest daily minimum and maximum temperatures were set in places in Romania.

The spring season brought positive anomalies over Eastern Europe (Fig. 7.31, MAM). Southern European Russia was especially warm in March, the other areas particularly in April and May. During May, the 500-hPa circulation featured a trough over Central Europe and a ridge over northwestern Russia whose impacts were the well-above-average temperatures in western Russia, with some areas recording anomalies exceeding +4.0°C.

The predominant event in summer was the exceptional heat wave in Eastern Europe, particularly European Russia, extending from early July to the middle of August (see Sidebar 7.7 for details).

In autumn, Eastern Europe experienced anomalous warmth on average, despite a cold October across almost the whole region. November, however, was much warmer than average except in northern European Russia, due to a broad ridge in the 500-hPa circulation over south-central Russia. This resulted in monthly mean temperatures of more than 4°C above normal over large parts of Eastern Europe.

December temperatures were significantly below average over most of Eastern Europe (except southern European Russia and eastern Ukraine). In northern European Russia, anomalies were below -5.0°C.

*(ii) Precipitation*

Precipitation totals in 2010 were generally close to normal in Eastern Europe (Fig. 7.32). Only Romania, Moldova, and small parts of Belarus and the Ukraine experienced precipitation totals above 125% of normal. Some central areas of European Russia had totals down to 50% of normal.

Winter precipitation was above normal in southwestern Eastern Europe and below normal in the northeast (Fig. 7.33, DJF). In January and February, precipitation was above average throughout Romania and Moldova.

In spring, the north and south of the region received above-average precipitation whereas the central parts were drier than normal (Fig. 7.33, MAM). In Romania, March was the third consecutive month with above-normal precipitation, particularly in the south. During May, wetter-than-normal conditions occurred over western parts of Eastern Europe, with some regions recording totals above the 90th percentile whereas eastern European Russia remained very dry.

Precipitation amounts in summer were below normal in most of Eastern Europe with a few exceptions in westernmost parts (Fig. 7.33, JJA). During June, the 500-hPa circulation featured a north-south dipole pattern of geopotential height anomalies with above-normal heights extending from Northern Europe to Mongolia and below-normal heights over central Siberia. This situation reflected a strong positive phase (+2.1) of the Polar/Eurasia teleconnection pattern (see http://gcmd.nasa.gov/records/GCMD_NOAA_NWS_CPC_POLAREUR.html for an explanation of this pattern). It was associated with exceptionally warm and dry conditions between the Black Sea and Caspian Sea where precipitation was below the 10th percentile. The mean precipitation signals during July indicated excess precipitation in Romania but below average totals (mainly below the 10th percentile) in European Russia, caused by a strong and persistent ridge over that area. August precipitation in Romania was above normal in the mountainous and western regions while precipitation amounts were low in the southeast, and even more so in the eastern Ukraine and southern European Russia.

Autumn precipitation totals were near normal or above average in Eastern Europe (Fig. 7.33, SON). November brought high monthly precipitation amounts to the region, within the upper tercile, except in the south.

Precipitation anomalies formed a tripole in December with a negative anomaly center north of 60°N and another over southern European Russia. Above-average totals, exceeding 250% of normal, were recorded in central areas.

#### *(iii) Notable events*

A week of heavy rains and subsequent floods between 20 and 30 June caused 24 deaths in northeastern Romania. The maximum 24-hour precipitation amount was 163.3 mm at Padureni. Nearly 10 000 houses were flooded and several roads and bridges suffered severe damage.

Maximum temperature records across European Russia affected animals in November. During the first half of November, temperatures in European Russia were around 10°C above average. The extreme temperatures meant that badgers and hedgehogs could not go into hibernation and some species of hares and red squirrel did not receive their warmer winter coats. This can negatively affect the animals when regular temperatures return.

### 7) Middle East—F. Maier, A. Obregón, P. Bissolli, and J. J. Kennedy

Israel, Cyprus, Jordan, Lebanon, Syria, western Kazakhstan, Armenia, Georgia, and Azerbaijan

#### *(i) Temperature*

Widespread anomalous warmth affected much of the Middle East in 2010 (Fig. 7.30). The average land surface air temperature anomaly ranged between +2°C and +4°C. It was the warmest year recorded in Israel since at least the middle of the 20th century.

In winter 2009/10, anomalies exceeded +2°C across almost the entire Middle East and +4°C locally. Western Kazakhstan was only slightly warmer than normal.

Warmer-than-average conditions also prevailed throughout the region in spring, mostly above +2°C. March was exceptionally warm in the Middle East, whereas during April and part of May, temperatures were colder than normal in western Kazakhstan and the southern Caucasus, up to 2°C below the monthly average.

Summer had high positive anomalies across the Middle East. Extreme weather conditions were recorded in Azerbaijan where national average anomalies surpassed +6°C. A heat wave during July in Armenia set an all-time record of 10 consecutive days with temperatures above 38°C. August was unusually warm for the Middle East, with positive anomalies exceeding +4.0°C in several areas. While the monthly normal temperatures in Cyprus were average in June and July, a monthly record was reached for August, +3.0°C above normal. On 1 August, the temperature in Athalassa was 45.6°C, the highest temperature ever recorded in Cyprus and 8.4°C above normal for August. Israel reported several heat waves, particularly in August, with record-breaking daily maximum temperatures above 45°C in some locations.

Temperatures during the remainder of the year were above average in all months, locally exceeding +4°C. Only western Kazakhstan had near-normal temperatures in October.

#### *(ii) Precipitation*

Annual precipitation was mostly below normal in the Middle East, only locally rising above average (Fig. 7.32).

Precipitation totals for winter were generally close to average for the Middle East, with a few positive deviations in western Kazakhstan, Armenia, and Cyprus, and negative anomalies in the south (e.g., Syria).

The spring was drier than average over the southeastern Middle East while the Caucasian areas and west Kazakhstan were wetter than average. In March, rainfall amounts in northern Israel were only 5 mm–15 mm (10% of normal); only two other years had comparably low rainfall in March in the last 70 years (1962 and 2004). April brought wet conditions to the south Caucasus, and many parts of Armenia received above-normal amounts of precipitation in May, up to nearly 250% of normal.

During summer, the southeastern Mediterranean region experienced near-normal precipitation amounts while Cyprus and the Caucasian countries had negative anomalies down to 30% of normal. In June, most of the southern Middle East experienced above-average precipitation totals, whereas the south Caucasus and west Kazakhstan were dry. Armenia had lower-than-normal June values down to 14% of normal. In contrast, Azerbaijan had intensive rainfalls at the beginning of June, causing severe countrywide flooding. July was especially dry in most of the Middle East except Armenia, Azerbaijan, and some local mountain sites in other parts. August

## SIDEBAR 7.7: SEVERE WINTER 2009/10 IN CENTRAL AND WESTERN EUROPE—F. MAIER, A. OBREGÓN, P. BISSOLLI, C. ACHBERGER, J. J. KENNEDY, AND D. E. PARKER

The climate patterns over Central and Northern Europe in winter 2009/10 were characterized by a strong negative North Atlantic Oscillation (NAO) and frequent attenuation of westerly air flow, resulting in severe cold spells across the region. The winter-average NAO index was the lowest since records began in 1821 (Fig. 7.37).

Snowstorms and negative temperature anomalies were the consequence (Fig. 7.31, DJF). Both Scotland and Ireland had their coldest winter since 1962/63; Ireland was 2°C below average. Many other countries in Western and Central Europe had their coldest winter since 1978/79 (UK was 1.6°C below average), 1986/87 (Germany, Switzerland), or 1995/96 (the Netherlands were 0.5°C below average). In January, the monthly temperatures were 1.5°C below normal in Austria and 2.2°C below normal in the Czech Republic. In February the Swiss meteorological office reported the coldest winter temperatures for its summit stations for up to 40 years.

The number of days with snowfall of 1 cm or more was higher than normal across the region. Northern Germany reported 20–40 more snow days and the Netherlands had an average of 42 days with snow (29 more than the long-term average), the highest value since 1979.

In the Baltic Sea, formation of sea ice started late after a relatively warm autumn with above-normal sea surface temperatures. Towards the end of 2009, very cold weather conditions over Scandinavia ensured a rapid development of the ice cover in the northern part of the Gulf of Bothnia, the Gulf of Finland, and Riga. Ice formation continued in all parts of the Baltic Sea until the middle of February and reached the maximum ice extent on 17 February (244 000 km$^2$), almost two weeks earlier than normal. Although the Baltic Sea ice season of 2009/10 is classified as a normal one, its impact on the maritime transport was considerable, with numerous traffic restrictions.

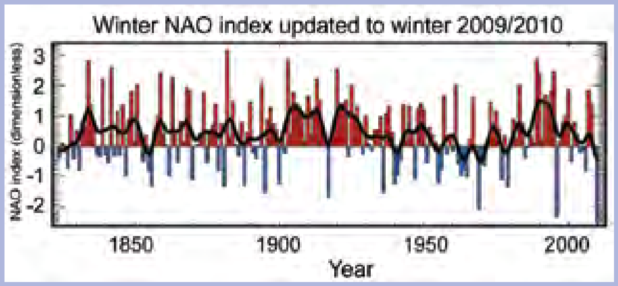


**Fig. 7.37. Time series of winter North Atlantic Oscillation (NAO) Index (after Jones et al. 1997, December–March average). (Image from http://www.cru.uea.ac.uk/~timo/datapages/naoi.htm, updated 28 Jan 2011.)**

One of the cold spells in January forced Frankfurt's airport to close over the weekend on 8 January. More than 90% of flights had to be cancelled. The anomalous cold also resulted in a blackout in the area around Leszno, Poland, where snow accumulated to a depth of 1.5 m. About 200 000 houses were left without power.

The UK Met Office reported January snowfalls to be the most significant and widespread across the UK since the mid-1980s. Thousands of schools were closed; there was severe disruption to transport networks, interruptions to water and electricity supplies to thousands of homes and businesses, and a number of fatal accidents related to the freezing weather conditions. In contrast to the cold and snowy conditions across Central and Western Europe, it was warmer and drier than usual in Greenland. This exceptional pattern reflected an extremely strong negative Arctic Oscillation (AO), the lowest December–February average since at least 1900 (compare Fig. 7.37 for the North Atlantic Oscillation). The persistent strong ridge of high pressure over Greenland enabled the advection of cold Arctic air far into Central Europe.

precipitation was mostly below normal in the Middle East and in the Caucasian countries.

The monthly Armenian precipitation totals continued to be low during September, but in October, Armenia had monthly rainfall amounts of 80 mm–120 mm (220%–250% of normal). Neighboring Caucasian countries had similar positive precipitation anomalies. November was again very dry for the whole Middle East. Middle Eastern countries close to the Mediterranean received less than 40% of the normal precipitation in November. In most parts of Israel, there was virtually no rain, making it one of the three driest November months in the last 70 years (only 1946 and 1966 were similarly dry).

*(iii) Notable events*

Heavy rainfall over Israel and Jordan on 17–21 January resulted in the worst flooding in over 10 years. The floods claimed the lives of 15 people and approximately 700 houses were engulfed. Precipitation totals of 70 mm were reported countrywide, a substantial fraction of normal monthly rainfall for most locations falling in only five days. For example, Jerusalem receives about 130 mm for the month of January on average.

On 12 March, heavy rainfall combined with melting snow resulted in severe floods in southern Kazakhstan. Over 40 people lost their lives and thousands of people were affected. This year's springtime floods were amplified by intense snowfall in the winter, followed by a rapid thaw.

On 2 December, a forest fire broke out close to Haifa, Israel. Dry conditions and strong winds helped it become the biggest wildfire in Israeli history. Over 41 people died in a bus that was caught in the flames, An estimated 17,000 people were forced to leave their homes, and almost 5000 hectares of land were burned.

On 11–12 December, an extratropical cyclone brought heavy rainfall and strong winds to the eastern Mediterranean and the Middle East. Five people lost their lives and shipping was disrupted in the Suez Canal. Along the coast of Lebanon, waves up to 10 m were observed. In Jordan, highways were closed because winds reached speeds above 90 km $hr^{-1}$.

## g. Asia

### 1) Russia—O. N. Bulygina, N. N. Korshunova, and V. N. Razuvaev

*(i) Temperature*

By and large, the year 2010 was warm in Russia. The annual temperature anomaly averaged over the Russian territory was +0.7°C (Fig.7.38). Temperature anomalies averaged over the Russian territory were positive for all seasons, except for winter (December 2009–February 2010, DJF), with the summer (June–August, JJA) temperature anomaly being the highest. Winter 2009/10 in Russia as a whole was one of the ten

## Sidebar 7.8: Summer heat waves in eastern Europe and western Russia—F. Maier, A. Obregón, P. Bissolli, C. Achberger, J. J. Kennedy, D. E. Parker, O.Bulygina, and N. Korshunova

Western Russia was affected during summer 2010 by extreme heat waves and very dry conditions, resulting in droughts, wildfires, and poor air quality. Temperature records with anomalies 4°C–8°C above normal were measured widely across the region (Fig. 7.34). The June–August temperature was 4.1°C above normal in central and southern European Russia. It was the hottest Russian summer in 130 years of record, on an areal average.

The heat wave started in early July, with increasing temperature maxima during that month. On 29 July, Moscow recorded its all-time highest temperature of 38.2°C, followed by further 32 consecutive days with temperatures exceeding 30°C. According to the governmental agency for the environment, the smog levels were five to eight times higher than normal. About 14 000 people lost their lives, half of them around Moscow alone. Over 20% of Russian crops growing on 8.9 million hectares of farmland were destroyed. There were more than 600 wildfires and 948 forest fires in 18 counties at the beginning of August, with thousands of people made homeless. Economic losses amounted to $15 billion (U.S. dollars). Adjacent countries such as Belarus, Ukraine, and Finland also recorded exceptional maximum temperatures. A record high number of extreme warm nights was reported in southeastern Europe.

According to NOAA's monthly *State of the Climate* report (http://www.ncdc.noaa.gov/sotc/2010/7), prior to 2010, the highest temperature recorded in Moscow was 36.8°C set 90 years ago. Russia is climatologically disposed toward blocking events during summer (Tyrlis and Hoskins 2007), and many of its prior July heat waves also were associated with such blocking patterns. Consistent with this, a composite analysis of the average temperature anomalies and 500-hPa heights associated with the ten largest prior heat waves in this region since 1880 shows patterns similar to 2010 (Barriopedro et al. 2011; Dole et al. 2011).

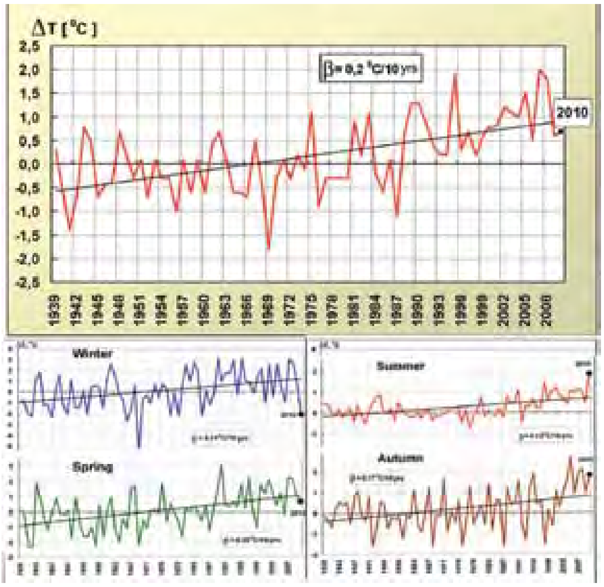


**FIG. 7.38. Anomalies of average annual and seasonal air temperatures averaged over the Russian territory for the period 1939–2010 (1961–90 base period).**

coldest winters in the instrumental record, associated with the extreme negative phase of the Arctic Oscillation (see Sidebar 7.7).

January 2010 was characterized by severe frosts over the large area covering southern Siberia and European Russia. Average monthly temperatures in the Novosibirsk and Kemerovo Regions and the Altai Territory, which were at the center of the cold island, were 9°C–10°C below normal. In Evenkia, on the first days of January, temperatures were even lower, -55°C. In central European Russia, average monthly temperature anomalies were 8°C to -8.5°C. Record temperature minima were recorded in Tambov, Ulyanovsk, and Penza, as well as some other cities. Such abnormally cold weather in central European Russia is related to a cold wedge of the Siberian anticyclone that propagated far westward. An important feature of January 2010 was a complete absence of thaws in Russia, which has been not recorded for several decades.

In February, Western Siberia experienced much-below-normal temperatures. The center of the cold island was above the Yamalo-Nenets Autonomous District, where average monthly temperature anomalies were -9°C to -11°C. On the coldest days, average daily temperature was 20°C–22°C below normal. Record-breaking temperature minima were recorded in both early and late February. Northern and northeastern European Russia experienced colder-than-usual weather. Severe frosts (-38°C to -46°C) were observed in the second part of the month (17–28 February). On 19 February, in the extreme northeastern regions of European Russia, the air temperature dropped to a record -52°C, which is the lowest February minimum temperature for the period of record. Meteorological station Hoseda-Hard registered the second lowest minimum temperature ever recorded in Europe, -57.0°C (Fig. 7.39). The lowest minimum temperature was registered at station Ust-Shugur, Komi Republic, in December 1978, -58.1°C. In early February, the first thaw set in central Russia and in the middle of the month, warm air from Africa reached Sochi, which led to a new record maximum winter temperature over the area of Russia, +23.8°C.

Spring 2010 over the Russian territory was generally warmer than the long-term average. March was warm over most of Western Siberia. Most of the Far East region experienced cold weather, particularly in Kamchatka and the southern Far East, where average monthly temperatures were 2°C–3°C below normal.

Over most of Russia, April was warm, especially in northeastern European Russia, where average monthly temperatures were 4°C–5°C above normal. In early April, record-breaking maximum temperatures were registered in northwestern European Russia (St. Petersburg, Pskov, Arkhangelsk, Kotlas, and Syktyvkar), and in the Urals region (Orenburg, Perm, Ufa, and Magnitogorsk). In the third ten-day period of April, record-breaking warm weather settled in southern Western Siberia. Although rivers were still icebound and snow was on the ground in places, temperatures rose as high as +25°C, the highest since 1972. Record-breaking cold weather was observed during the first week of the month in Kolyma and eastern Yakutia. In Oimyakon, which is known as "cold pole", a new daily minimum temperature was set.

May 2010 was warmer than the long-term average. As early as the beginning of the month, record-breaking temperatures were registered in northern European Russia, Upper and Mid-Volga, the Urals region, and central Russia, where average daily air temperatures were 7°C–11°C above normal. Unusually warm weather propagated from central European Russia outside the Arctic Circle. By the end of the first ten-day period, average daily temperature anomalies were larger than +10°C. On 11 May, record-breaking maximum temperatures were recorded in many northern cities (Naryan-Mar, Pechora, and Syktyvkar). Weather in northern European Russia was warmer than in the south. On 18 May, air temperature in Murmansk reached 26.4°C, nearly 5°C higher than the previous record set in 1984.

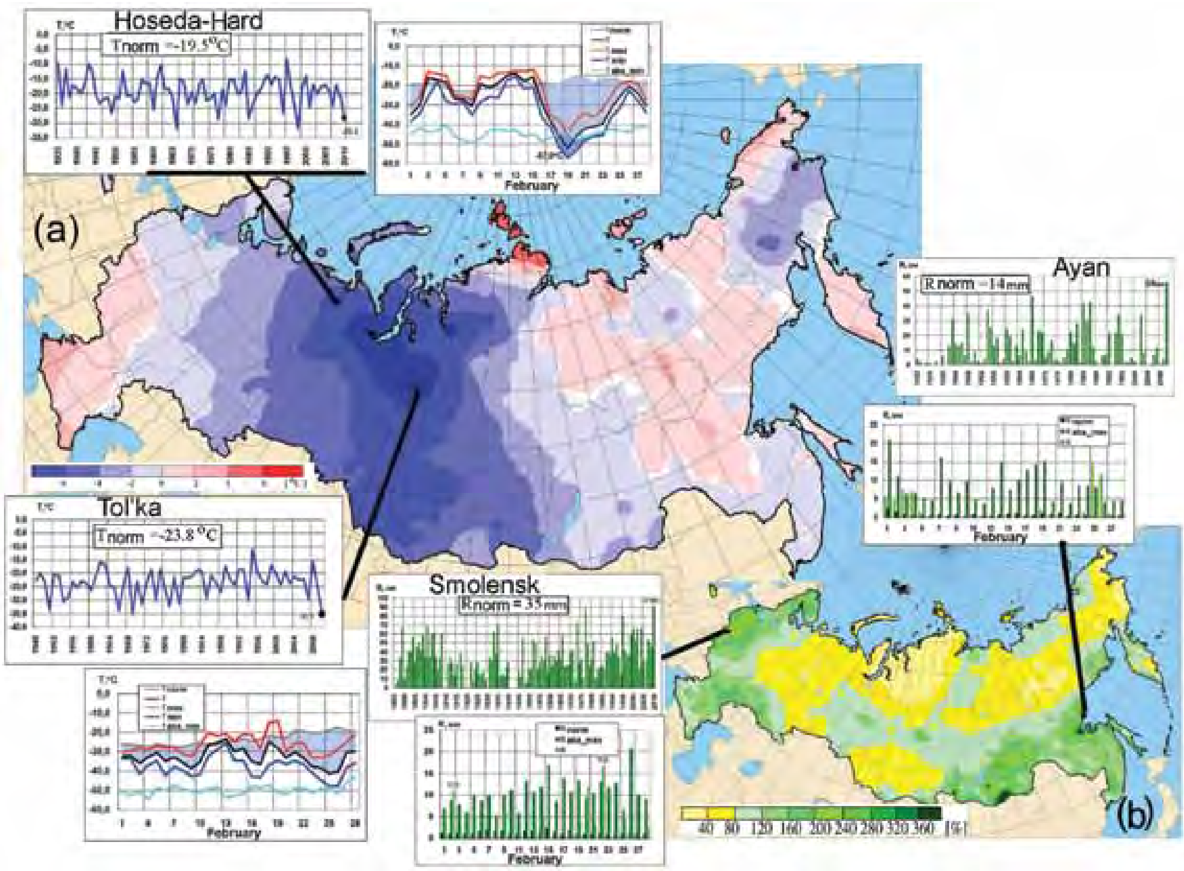


**Fig. 7.39. Weather conditions for Russia in February 2010, showing (a) air temperature anomalies. Insets show the series of average monthly air temperatures and average daily temperatures during February at meteorological stations Hoseda-Hard and Tol'ka and (b) percentage of monthly precipitation totals. Insets show monthly precipitation total series and daily precipitation during February at meteorological stations Smolensk and Ayan.**

Summer in Russia was the warmest such period on record, with a temperature anomaly of +1.8°C (Fig. 7.38). It was particularly warm in central and southern European Russia, where the seasonal temperature anomaly was +4.1°C.

In June, positive temperature anomalies prevailed over the Russian territory. In European Russia, a heat island formed over the Volga region and the Southern Urals, where average daily air temperatures were 7°C–11°C above normal; maximum daily temperatures reached 33°C–38°C. On 25 June, a maximum temperature record was also set in Moscow, 32.8°C. In southern Siberia, strong heat with maximum temperatures of 33°C–43°C persisted throughout the third ten-day period of the month. In Chita and most other cities of the region, record daily maximum temperatures were observed. June temperature records were also broken in many southern regions of the Far East. On 9 June, the temperature in Vladivostok reached 29.9°C, which is more than 3°C above the record previously set in 1969. Such weather is atypical for early summer in the Maritime Territory, where the weather is usually dull, moist, and cool, due to monsoon effects.

July 2010 became the hottest July on record in Russia, despite the fact that over much of the country (Urals and Western Siberia) it was substantially colder than normal. For an extended period, most regions in European Russia experienced extreme heat due to a stationary anticyclone that brought hot air from Central Asia. Nearly every day brought new temperature records. Abnormally hot weather settled in northern and eastern Yakutia on 1–5 July, with average daily temperatures 8°C–12°C above normal. On 4 July, a new daily record maximum temperature of 30.6°C was established in Oimyakon. A record maximum temperature of 32°C was set on 19 July in the north of Kamchatka. Western Siberia was the only Russian region where average monthly July temperature was below normal. In Surgut, a new record minimum temperature of 3.5°C was established on 20 July.

During the first half of August, most of European Russia experienced abnormally hot weather. However, the heat island that formed above central European Russia in July moved slightly southward. In the third ten-day period of August, high temperatures declined in central and eastern European Russia and the first frosts were recorded in the Urals, Upper Volga, and Northwestern regions (see Sidebar 7.8 for further details about this heat wave).

In September, maximum average monthly temperature anomalies were recorded in Chukotka (4°C–5°C). Average monthly temperatures over European Russia were above long-term averages. In the third ten-day period, the Urals region was in the warm rear part of the anticyclone that moved to Kazakhstan. Therefore, sunny and dry weather prevailed. Temperatures reached 25°C–28°C, which was 7°C–10°C above normal, resulting in new maximum temperature records.

October in the Urals region, Western Siberia, Chukotka, and Kamchatka was very warm. In the Altai Territory, maximum temperatures reached 13°C–15°C. October was colder than the long-term average over most of European Russia (except for northern and northeastern European Russia). In early October, an extensive cold anticyclone led to new daily minimum temperature records in Tver, Tula, Saratov, and other cities. In most of the Upper Volga regions, snow cover formed ten or more days earlier than their respective long-term averages.

November was abnormally warm over most of the Russian area. The first half of the month was particularly warm over most of European Russia and southern Western Siberia. In many cities (Smolensk, Tver, Vladimir, Kostroma, Nizhni Novgorod, Izhevsk, Cheboksary, Bryansk, Kursk, and Lipetsk), new temperature records were set. Warm and moist Atlantic air masses moving to Siberia over European Russia brought warm rainy weather to southern Western Siberia. On the last days of the month, cold Arctic air masses over European Russia transported warm air southward and genuine winter came to the central regions. In late November, winter weather also settled in northern Western Siberia. The Taimyr Peninsula and Evenkia experienced hard frosts in the third ten-day period of the month (-40°C to -47°C).

A large cold island formed over the Russian territory in December. The island had two centers, one of which was located above northwestern European Russia and the other above central Eastern Siberia. Average monthly air temperature anomalies were -6°C to -7°C and -8°C to -10°C, respectively. December was warm in southern European Russia, with average monthly temperature anomalies greater than +7°C to +8°C in individual regions. On the Black Sea coast, daily temperatures rose as high as 25°C. In the North Ossetia valleys, tree buttons swelled and roses bloomed and in some villages, strawberries bloomed. On 26 December, the temperature in Stavropol reached 17.1°C, breaking the record previously set in 1954 by 6°C. A more extensive warm island formed over the northeastern Far East. Average monthly temperature anomalies were more than +10°C. At meteorological station Omolon, the average monthly temperature was -23.1°C, compared with the normal value -35.8°C.

#### *(ii) Precipitation*

Precipitation over Russia was generally near normal (80%–120%) for 2010 as a whole. Above-normal precipitation was recorded in northwestern European Russia and in some areas of southern Siberia (120%–140%). Precipitation deficit was recorded in central European Russia (< 80%).

In February, a precipitation deficit was recorded in northeastern European Russia and northern Western Siberia due to prevailing anticyclones. Western and southern European Russia received considerably more precipitation, more than twice the monthly average in some places. Smolensk (Fig. 7.39b) received 90 mm of precipitation, compared with the normal value of 35 mm—the highest February precipitation on record since 1885. The southern Far East also received much-above-normal precipitation. At some stations, record-breaking monthly precipitation totals were observed.

In March, much-above-normal precipitation (more than two to three times the respective monthly averages) was recorded in Northern Caucasia and in southern Western Siberia. In May, much-below-normal precipitation was recorded in eastern European Russia and in the northeastern Far East.

Central and southern European Russia experienced a substantial rainfall deficit in June. During the last ten-day period of June, the Central and Volga Federal areas, as well as Lower Volga received no or a few millimeters of rainfall. In July, a precipitation deficit was registered in European Russia (4%–40% of monthly normal). In August, precipitation deficit was registered over the area from the Upper Volga region to the southern regions in European Russia. During this month, drought spread farther south: Rostov

Region, Krasnodar and Stavropol Territories, and republics of Northern Caucasia. The southern part of Western Siberia received below-normal precipitation.

In September, much-above-normal precipitation (more than three to four times the monthly averages) was recorded in the east of Russia (Kamchatka, Chukotka, and eastern Yakutia). In October, southern European Russia received above-average precipitation, especially the Astrakhan Region and the Republic of Kalmykia, where the monthly precipitation totals were three to five times higher than normal.

In December, much-above-normal precipitation was recorded in some regions of the Far East. Monthly rainfall was four to five times higher than normal in many locations. Petropavlovsk-Kamchatsky was inundated with heavy rains throughout the first half of the month (high temperatures turned snow into rain). On 9 and 11 December, daily precipitation records were set and the monthly precipitation total, 446.3 mm, was the highest on record for December at the station. Heavy snowfalls in the southern Far East were the highest amounts recorded in the past 60 years. At many stations, monthly precipitation was four to five times higher than normal.

*(iii) Notable events*

Due to heavy snowfalls, avalanche-hazardous conditions and human-induced avalanching were recorded in the mountains of Northern Caucasia in February.

In March, in the third ten-day period, spring floods were recorded on the rivers in southern European Russia. Due to significant snow accumulation during the winter, despite preventive measures taken, a very complex hydrological situation existed on the rivers of the Voronezh, Volgograd, and Rostov regions (e.g., Don, Medveditsa, Khoper, Ilovlya, and Chir). In places, water levels rose to six to seven meters, which resulted in the inundation of many houses and evacuation of residents.

Due to large snow accumulation, torrential spring floods were recorded in May in Western Siberia. Particularly complex hydrological situations existed on the Ob, Chaya, Chulym, Peschanaya, and Tom rivers. Break-up of the Tom River in the vicinity of Tomsk was accompanied by ice clogging with an abrupt water level rise.

In the first ten-day period of May, abnormally hot weather settled central European Russia; maximum daily temperatures reached 28°C–31°C. As a result, the area experienced hot winds and extreme fire hazards. Forest fires were registered in the Lipetsk and Tambov regions.

In June, hot weather, combined with significant rainfall deficits and strong hot winds, contributed to severe soil moisture deficits and drought conditions. Abnormally hot and dry weather gave rise to extreme fire hazards in central European Russia. In the last ten-day period it was very hot in the Altai Territory, where temperatures reached 36°C in places. Hot winds and soil drought were observed in the northern Altai Territory and steppe areas of the Kemerovo Region. Hot and dry weather contributed to forest fires.

In July, a combination of abnormally hot weather and substantial rainfall deficit (4%–40% of monthly normal) observed in many regions resulted in damage, crop destruction, and forest fires over vast areas.

In August, extreme fire hazards persisted and forests and peat bogs were still on fire. During the first days of August, dense smog wrapped Moscow, Ryazan, and other cities. A fire that engulfed the roads and led to zero visibility brought traffic along highway Moscow-Chelyabinsk to a standstill and disturbed railroad movement.

Heavy rains (47 mm–93 mm) that occurred on 15–16 October in the Apsheron and Tuapse Regions of the Krasnodar Territory caused an abrupt water level rise on local rivers (3.40 m–9.16 m). Fifteen people were killed.

Freezing rain was observed in central regions of European Russia on 25–26 December. Operations at large Moscow airports were brought to a standstill

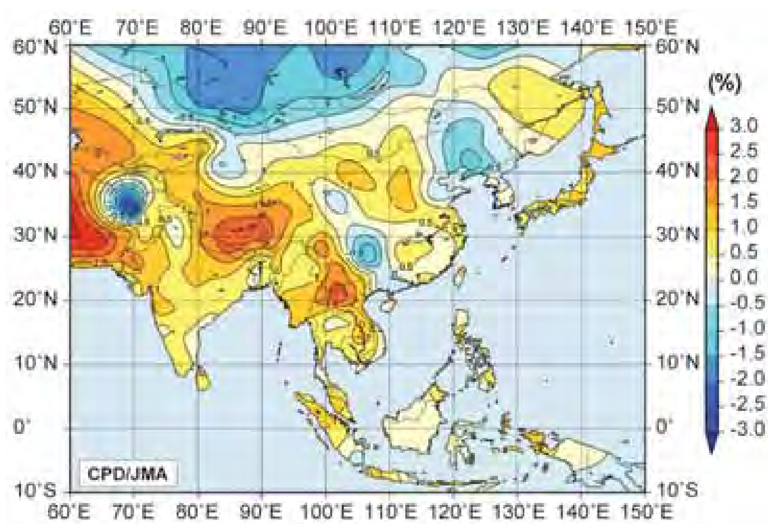


**Fig. 7.40. Annual mean temperature anomalies (°C; 1971–2000 base period) over East Asia in 2010. (Source: Japan Meteorological Agency.)**

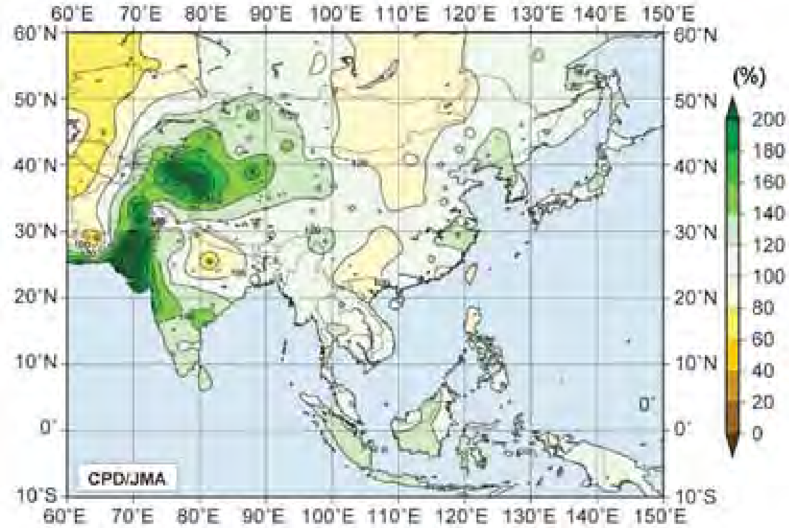


**Fig. 7.41. Annual precipitation ratio as percentage of normal (1971–2000 base period) over East Asia in 2010. (Source: Japan Meteorological Agency.)**

owing to ice glaze and hundreds of settlements in the Smolensk, Moscow, and Nizhniy Novgorod Regions lost their electricity supply.

2) East Asia—P. Zhang, Y. Liu, and H. Ishihara

Countries considered in this section include: China, Korea, Japan, and Mongolia.

*(i) Overview*

Annual mean temperatures across East Asia showed a nonuniform pattern in 2010 (Fig. 7.40), with negative anomalies over southern and northern China and the Korean Peninsula, and positive anomalies over Japan, central China, and parts of Mongolia. Annual total precipitation was near normal in most regions (Fig 7.41).

*(ii) Temperature*

The average temperature over China for 2010 was 9.5°C, 0.7°C above the 1971–2000 average, ranking as the 10th warmest year since 1961 and the 14th consecutive above-average year since 1997. Annual mean temperatures for 2010 were above normal over most of China except central and southern Northeast China, some part of eastern North China, and northern Xinjiang, and 1°C–2°C above normal in Northwest and Southwest China. Seasonal mean temperatures were higher than normal in all seasons of 2010, except for spring. The seasonal surface temperature anomalies over China were 0.7°C, -0.1°C, 1.1°C, and 1.0°C for winter, spring, summer, and fall respectively. The spring temperatures in China were below normal for the first time since 1997. However, the summer was the warmest since 1961. In 2010, the annual mean number of hot days (daily maximum temperature ≥ 35°C) all over China was 11.1 days, 4.1 days more than normal and ranked the highest frequency since 1961.

The average surface temperature over Japan (averaged over 17 observatories confirmed as being relatively unaffected by urbanization) in 2010 was 0.86°C above the 1971–2000 average, making 2010 the fourth warmest year since 1898. Area-averaged annual mean temperature anomalies were +1.0°C in northern Japan, +1.0°C in eastern Japan, +0.8°C in western Japan, and +0.4°C in Okinawa/Amami. In 2010, Japan experienced the hottest summer in more than 100 years. The three-month mean temperature for June–August in Japan was the highest in the historical record held by Japan Meteorological Agency that dates back to 1898, 1.64°C above the 1971–2000 average. In particular, August was so warm that monthly mean temperature records for August were broken at 77 out of 144 observatory stations in Japan.

*(iii) Precipitation*

The mean annual precipitation averaged across China was 681.0 mm, 11.1% above normal, which ranked the second highest since 1961 (highest was 14% above normal in 1998). Moreover, the precipitation in each season was above normal, especially in spring, which ranked the second highest since 1961. The annual number of rainstorm days were 21.5% more than normal and ranked the third highest since 1961. The rainstorms occurred mainly in southern Northeast China, middle and lower reaches of Huanghe River and Yangtze River Basin, and South China.

In 2010, there were frequent extreme weather and climate events caused by extreme precipitation. As a result of receiving 30% to 80% less-than-normal precipitation from September 2009 to March 2010, Southwest China experienced a rare severe autumn-winter-spring drought. During January–March, the most serious snowstorm struck northern Xinjiang, with 36 days and 94.8 mm of average precipitation, breaking the previous historical record. From May to July, heavy rainstorms struck southern China 14 times, bringing 800 mm–1200 mm accumulated precipitation in some areas from south of the Yangtze River to southern China. From mid-July to early-September, severe rainstorms and induced flooding also struck northern and western China 10 times. From 1 to 19 October, seldom-consecutive heavy rainstorms appeared in Hainan where the regionally-averaged precipitation was 1060 mm, ranking highest since 1951. Serious geological hazards such as mountain torrents and mud-rock flow occurred in Zhouqu of Gansu province and other isolated places.

In Japan, due to cold spells, many parts on the Sea of Japan side of the country were hit by heavy snow during the first half of January and the first ten days of February. In early February, Niigata, on the Sea of Japan side in eastern Japan, received up to 81 cm of snow, the deepest since a fall of 87 cm during the 1983/84 winter. Since cyclones and fronts frequently passed near the mainland of Japan, seasonal precipitation amounts were significantly above normal in northern, eastern, and western Japan in spring. Seasonal precipitation was significantly above normal on the Sea of Japan side in northern Japan due to the influences of fronts in summer. Seasonal precipitation amounts were significantly above normal in Okinawa/Amami in autumn.

The South China Sea summer monsoon (SCSSM) broke out in the fifth pentad of May (near normal) and withdrew in the fifth pentad of October (five pentads later than normal). The intensity of the SCSSM was -3.9, which was the weakest year since 1951. The SCSSM was much weaker than normal as a whole except for two periods: one from the fifth pentad of May to the first pentad of June and one during the first two pentads of September. After the full onset of the SCSSM, the front of the East Asian subtropical summer monsoon (EASSM) maintained over the region from South China to the south of the Yangtze River from the fifth pentad of May to June. In the first pentad of July, the front of the EASSM advanced to a region from the middle and lower reaches of the Yangtze River to the Yangtze-Huaihe River basins. With the northward movement of the monsoon surges and the subtropical high over the western North Pacific, the major rain belt in eastern China correspondingly moved northward. In June, the rain belt was mainly located in the south of the Yangtze River. From the first to third pentad of July, the major rain belt advanced to the middle and lower reaches of the Yangtze River. From the fourth to fifth pentad of July, the rain belt continued to move northward, with a large area of rainfall in the Yangtze-Huaihe and Yellow-Huaihe river basins. In fifth pentad of August, the front of the EASSM advance to North China and then North China entered the rainy season. In the second pentad of September, with the ridge of the subtropical high retreating southward, the rain belt in eastern China shifted from southern Northeast China and North China to southern North China and the Huanghe-Huaihe River basins. During late September, the warm and wet air swiftly retreated southward to regions south of 25°N. Due to the active tropical storm systems during this period, the warm and wet air remained there about one month, which resulted in persistent precipitation over South China and the South China Sea. In the fifth pentad of October, with the cold and dry air from North China intruding to the coastal areas and the northern South China Sea, thermodynamic properties of the air mass over the South China Sea changed. The front of summer monsoon then began to withdraw from the South China Sea and the SCSSM ended.

*(iv) Notable events*

There were 14 named tropical cyclones formed over the western North Pacific and the South China Sea in 2010, significantly less than the 1971–2000 average frequency of 26.7 and the lowest number since 1951. Super Typhoon Megi developed intensively with a central surface pressure less than 900 hPa. After hitting the Philippines, the storm turned northward in the South China Sea, causing damage to southern China and Taiwan. From November to December, for the first time since 1951, no named tropical cyclones formed in this region (see section 4d4 for further details on the 2010 western North Pacific hurricane season).

In early May, the strongest wind and hail storms of the past 20 years occurred in Chongqing China, with local maximum wind speed more than 108 km $hr^{-1}$, and causing heavy casualties.

In spring 2010, China was affected by 16 dust and sand storms, which was below the normal frequency for 1971–2000 but more than the 2000–09 decadal average of 12.7. The average number of dust days in northern China was 2.5 (3.1 days less than the 1971–2000 average). During 19–22 March, a strong dust storm affected 21 provinces in China, which was the widest influence in 2010.

Meanwhile, Kosa (yellow sand/aeolian dust) events were observed at 58 of 61 stations in Japan on 21 March 2010, marking the highest number on record. Also significant in 2010 were new records set in May, November, and December in terms of the number of days when any meteorological station in Japan observed Kosa. There were 41 days in which any meteorological station in Japan observed Kosa in 2010, nearly double the normal number (20.1 days). A cumulative total of 526 observations of Kosa were made in 2010, more than triple the average of 153.9.

### 3) South Asia—M. Rajeevan, A. K. Srivastava, Z. Lareef, and J. Revadekar

#### (i) Temperatures

South Asia continued to experience unusually warm temperatures in 2010. The summer months of March, April, and May were characterized by abnormally high temperatures over northern/northwestern parts of India and Pakistan with many days of extreme heat wave conditions.

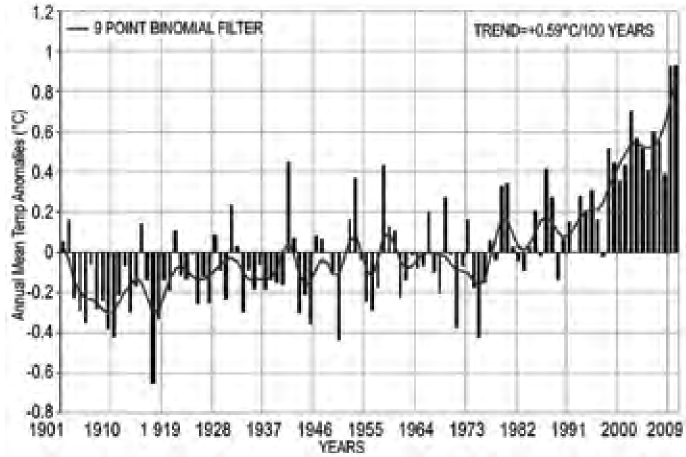


**Fig. 7.42. Annual mean temperature anomalies (with respect to 1961–90 normal) averaged over India for the period 1901–2010. The smoothed time series (9-point binomial filter) is shown as a continuous line.**

The annual mean temperature for India was 0.93°C above the 1961–90 average, making 2010 the warmest year on record since nationwide records commenced in 1901 (Fig. 7.42). This superseded the previous five warmest years, which have all occurred since the turn of the century: 2009 (+0.92°C), 2002 (+0.71°C), 2006 (+0.60°C), 2003 (+0.56°C), and 2007 (+0.55°C). Mean monthly temperature anomalies over the country as a whole were the highest for March (+2.27°C), April (+2.02°C), and November (+1.17°C), and the second highest for May (+1.17°C), since records began in 1901. The recent decade (2001–10) was the warmest decade on record over India with a decadal mean temperature anomaly of +0.60°C.

#### (ii) Precipitation

The summer monsoon season (June–September) contributes 60%–90% of the annual rainfall over major portions of South Asia. During the 2010 monsoon season, while India, Pakistan, and Sri Lanka experienced above-normal rainfall activity, Bangladesh experienced its driest monsoon since 1994.

For India, the long-term average (LTA) value of the summer monsoon rainfall, calculated using all data from 1941 to 1990, is 890 mm. For 2010, the summer monsoon seasonal rainfall over India was 102% of its LTA. During the season, the monsoon trough (an east-west elongated area of low pressure) was mostly located south of its normal position and monsoon low pressure systems moved south of their normal tracks. This resulted in an uneven spatial distribution with above-normal rainfall over peninsular and northwest India and deficient rainfall over central and northeastern parts of India (Fig. 7.43). Consistent with the recent decreasing trend of the frequency of monsoon depressions over the Indian Ocean, none of the 14 low pressure systems formed over the Bay of Bengal intensified into a monsoon depression.

The monsoon advanced into southern parts of India on 31 May, close to its normal schedule. However, formation of Tropical Cyclone Phet over the Arabian Sea disrupted the northward progress of the monsoon and caused a prolonged hiatus of about two weeks. The slow progress in the monsoon advancement resulted in a rainfall deficiency of 16% for June over the country. However, the rainfall activity in July, August, and September months was normal with monthly rainfall of 103%, 105%, and 110% of LTA respectively. During the season, of the 36 meteorological subdivi-

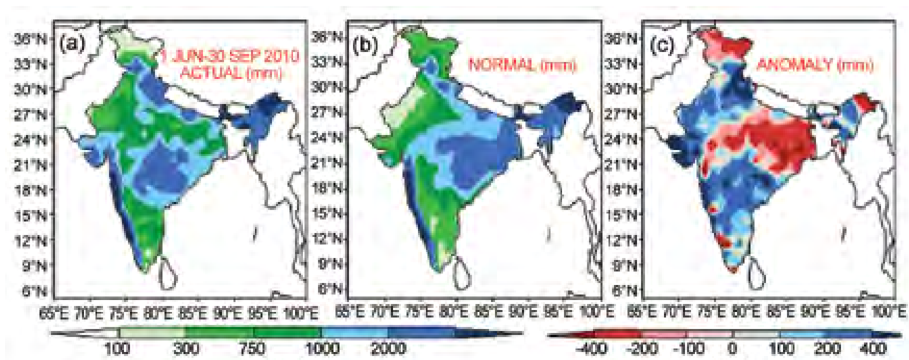


**Fig. 7.43. Spatial distribution of 2010 monsoon seasonal (June–September) rainfall (mm) over India.**

sions, 14 received excess rainfall, 17 received normal rainfall, and the remaining five subdivisions received deficient rainfall.

Pakistan, which is at the western edge of the pluvial region of the South Asian monsoon, experienced the worst flooding in its history as a result of exceptionally heavy monsoon rains (Fig. 7.41). The flooding was caused by a major rain spell from 28 to 29 July, when the rainfall totals exceeded 120 mm over a large area of northern Pakistan. There were additional heavy rains further south from 2 to 8 August (Webster et al. 2011). During the following days, flooding extended through the entire Indus Valley, leaving behind a wake of devastation and destruction. The death toll was close to 2000 and over 20 million people were affected. The agricultural losses were estimated at more than $500 million (U.S. dollars). Over the northwest and central parts of the country, the seasonal rainfall was more than 75% above normal. The total monsoon seasonal rainfall in 2010 was the fourth highest on record and the highest since 1994. These heavy rainfall events over Pakistan could be attributed to an interaction of extended monsoon flow and an upper level trough in the westerly jet stream. The persistent trough in the jet stream associated with the upper-layer blocking pattern over West Asia caused strong upper-layer divergent flow and ascent of warm and moist surface air. Near the surface, the monsoon easterly winds extended unusually far along the Himalayan foothills into northern Pakistan.

Since the monsoon trough was mostly located south of its normal position, the rainfall activity was subdued over Bangladesh. The monsoon season typically brings the country more than 75% of its annual rainfall. In 2010, Bangladesh experienced one of the driest monsoon seasons since 1994, with the seasonal rainfall about 19% less than the 30-year long term average rainfall.

The northeast monsoon (NEM) contributes 30%–50% of the annual rainfall over southern peninsular India and Sri Lanka as a whole. Over south peninsular India, active monsoon conditions continued unabated during the NEM season also. Above-normal rainfall activity over the region was associated with the presence of an active Intertropical Convergence Zone (ITCZ) across the region and formation of five low pressure systems (two severe cyclonic storms, two depressions, and one low pressure area) over the warm waters of the south Bay of Bengal. The 2010 NEM seasonal rainfall over south peninsular India was significantly above normal (155% of LTA), which is the second highest since 1901, behind 2005.

Rainfall over Sri Lanka was up to 30% below normal during January–March, was wetter than normal from July to September and, after a dry October, was much wetter than normal during November and December. The rainfall anomalies during January–March were typical of anomalies during an El Niño episode that prevailed until April 2010 and the wet anomaly from June to September was typical of that during the La Niña event that commenced in July. However, the enhanced rainfall (more than 50% above normal) during the main planting season from October to December was anomalous but not unprecedented. During La Niña episodes, there is usually below-normal rainfall (Zubair and Ropelewski 2006) but in the 43 La Niña events from 1869 to 1998, wet conditions were reported on six occasions. The cumulative impact of wet conditions since April led to many landslides and floods that intensified to the end of the year.

*(iii) Notable Events*

Severe cold wave conditions with temperatures 5°C–10°C below normal prevailed over northern parts of India in January and during the first fortnight of February, claiming more than 600 lives. On 18 April, Delhi, the capital city of India, recorded its highest April temperature (43°C) in nearly 60 years. In May, severe heat wave conditions with daytime temperatures 4°C–5°C above normal prevailed over northern and central parts of India claiming more than 300 lives. In Pakistan, record daytime temperatures were reported for several days during the last week of May; the heat wave conditions claimed at least 18 lives. A maximum temperature of 53.7°C was recorded at Mohenjo-daro on 26 May. This was the warmest temperature ever recorded in Pakistan and possibly the fourth warmest temperature ever recorded anywhere in the world.

On 13 April, a severe convective storm with strong winds of more than 26 m $s^{-1}$ caused widespread damages in West Bengal and Bihar, claiming more than 120 lives, and leaving nearly one million people homeless. The severe cyclonic storm Laila that formed over the southeast Bay of Bengal, crossed the Andhra coast on 20 May, causing widespread damage and claiming the lives of more than 50 people. An unusually heavy rainfall event in the early hours of 6 August in Leh (Jammu and Kashmir) claimed more than 150 lives and more than 500 people were reported missing. Rainfall records for India during 2010 are listed in Table 7.2.

**Table 7.2. Record rainfall over India during the 2010 monsoon season**

| S. NO. | Station | 24-hr Rainfall (mm) | Date | Previous record (mm) | Date of record | Year of Record |
|---|---|---|---|---|---|---|
| | | | **June** | | | |
| 1 | N. Lakhimpur | 207.8 | 16 | 183.0 | 22 | 1990 |
| 2 | Osmanabad | 111.2 | 23 | 68.2 | 3 | 2000 |
| 3 | Cial Cochi | 160.6 | 13 | 93.9 | 6 | 2004 |
| | | | **July** | | | |
| 1 | Phoolbagh | 146.2 | 21 | 123.6 | 11 | 2003 |
| 2 | Damoh | 253.6 | 26 | 225.1 | 18 | 1973 |
| 3 | Okha | 330.5 | 27 | 283.3 | 10 | 1973 |
| 4 | Nandyal | 143.2 | 11 | 116.0 | 16 | 1989 |
| 5 | Dharmapuri | 117.0 | 9 | 91.6 | 12 | 1989 |
| | | | **August** | | | |
| 1 | Okha | 226.5 | 3 | 119.8 | 11 | 1981 |
| 2 | Bhira | 380.0 | 30 | 350.0 | 23 | 1997 |
| 3 | Osmanabad | 149.8 | 22 | 85.0 | 21 | 2009 |
| 4 | Arogyavaram | 111.0 | 21 | 90.0 | 9 | 1970 |
| | | | **September** | | | |
| 1 | Ranchi AP | 205.8 | 12 | 168.4 | 28 | 1963 |
| 2 | Pant Nagar | 117.2 | 7 | 105.0 | 10 | 1967 |
| 3 | Bharatpur | 107.0 | 4 | 91.8 | 17 | 1990 |
| 4 | Dhar | 170.8 | 8 | 151.0 | 21 | 1973 |
| 5 | Narsapur | 115.7 | 13 | 88.9 | 24 | 1997 |
| 6 | Mangalore AP | 150.2 | 24 | 125.5 | 6 | 1902 |
| 7 | Panambur | 125.2 | 24 | 113.6 | 26 | 1998 |
| 8 | Belgaum (AP) | 150.0 | 24 | 100.4 | 20 | 1981 |
| 9 | Cochi AP | 183.5 | 24 | 128.0 | 28 | 2009 |
| 10 | Cial Cochi | 108.0 | 24 | 77.4 | 18 | 2009 |

#### 4) Southwest Asia

##### *(i) Iraq*—M. Rogers

###### *(A) Temperature*

Temperatures in Iraq during 2010 were 2°C–4°C above normal. Many locations had above-average temperatures every month, with temperatures reaching at least 50°C in many central and southern areas during the summer. Figure 7.44 shows the seasonal temperature anomalies for three locations.

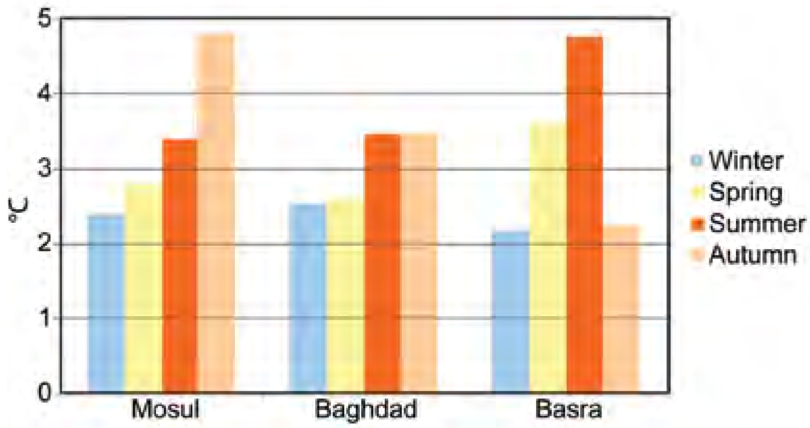


**Fig. 7.44. 2010 seasonal temperature anomalies (°C) for three Iraqi cities compared with 1961–90 normal.**

Winter temperatures, as with the rest of the year, were significantly above average, with most locations having no frost at all. The airbase at Tallil in the south did have a couple of nights where the temperature fell below freezing during the late winter but overall the season was still above normal. Spring followed in a similar pattern with some locations having record daytime temperatures. Summer and autumn continued to be well above average across most areas although temperatures were closer to normal during November in the south.

*(B) Precipitation*

Rainfall over Iraq was well below average across all areas for the third consecutive year. The winter period, December 2009–February 2010, was the wettest part of the year. December 2009 was wetter than normal at Mosul but elsewhere, and for the rest of the season, it was significantly drier than average. Below-average rainfall continued for the rest of the year, with the dry summer conditions continuing well into the autumn. Mosul received above-average rainfall during December as the 2010/11 winter began unsettled in the north while drier-than-normal conditions continued across central and southern areas.

*(C) Notable Events*

The major event of 2010 was the continued drought, especially during the autumn. For the third consecutive year, below-average rainfall had a major effect on the country's agriculture. The drought led to falling river levels in the Tigris and Euphrates. Further, dust storms occurred more frequently during the year and fog occurred less.

*(ii) Iran*—M. Khoshkam and F. Rahimzadeh

*(A) Temperature*

Warmer-than-average conditions occurred during winter 2009/10 (Table 7.3). The highest values occurred in parts of northwest including West Azerbaijan, East Azerbaijan, and Kordestan provinces, with anomalies of +5°C with respect to the long-term mean. The highest anomalies occurred in Ghorveh, Kordestan, with +7°C anomalies. During spring, the country experienced temperatures mostly 0°C–2°C above the long-term mean; however, in some small parts of central Iran, temperature anomalies were +2°C to +3°C. And in some isolated areas, mean temperatures were up to 0.8°C below average. In the summer, a vast area, including some parts of northeast and central Iran, reported mean temperatures that were 0°C–1.7°C below average. The rest of the country experienced temperatures 1°C–2°C above

**Table 7.3. Seasonal amount of precipitation and temperature over Iran 2010.**

| Parameter / Season | | | Winter | Spring | Summer | Autumn |
|---|---|---|---|---|---|---|
| Precipitation | Average (mm) | | 75.4 | 62.9 | 6.63 | 19.3 |
| | Respect to (%) | Long term | 31% | 30% | 34% | 72% |
| | | previous year | 23% | 20% | 47% | 78% |
| | Range from–to (mm) | | 0.5–450.5 | 0–310 | 0–324 | 0–586 |
| Temperature | Respect to long term (°C) | | 0.5 to 7 | -0.8 to 3 | -1.7 to 4 | -0.5 to 6.5 |
| | Range from-to (°C) | | -1.7–23 | 8–33 | 15–41 | 5–30 |

*red: above long term, blue: below long term, dashed: mixed below and above long term the long term average, although anomalies of up to +4°C were experienced at two stations. In autumn, warmer-than-average temperatures persisted across the country, while cooler-than-average conditions were limited to a small part in the southeast. The highest positive anomalies were in the northwest and in some parts of the Caspian Sea area, where temperatures were around 2.5°C above the long-term average. Khore-Birjand station in eastern Iran recorded a +6°C anomaly, while Zahedan in the southeast recorded an anomaly of 0.5°C.

Comparing patterns of average seasonal temperatures, anomalies over the country tended to be uniform (except in spring), with the northwest exhibiting larger positive anomalies than other areas. This part of the country is a mountainous area with low average temperatures. Such a pattern has been projected by climate models, as discussed in a joint project by the Atmospheric Science and Meteorological Research Center in Tehran (http://www.asmerc.ac.ir/) and the Climatological Research Institute in Mashhad (http://www.irimo.ir/english/index.asp). In summer, the central part the country was warmer than other regions, where temperatures were mostly below normal.

#### *(B) Precipitation*

Iran experienced drier-than-normal conditions for winter, summer, and autumn in 2010 (Table 7.3). Spring, summer, and autumn also received less rainfall in 2010 than in 2009. During winter, areas with average or above-average rainfall (up to 170% of normal) were confined to parts of the northeast, northwest, southeast, and small parts of the Zagross mountains, while the rest of the country received precipitation amounts no more than 90% of normal. However, total winter rainfall in Golpaygan and through western parts of the country was up to 400% of normal. Similar to 2009, the largest total winter rainfall of 450 mm was observed in Koohrang, located in the Zagross mountain area. Through the middle and east of the country, and in localized regions in Hormozgan province (across the Persian Gulf), rainfall was less than 25 mm. In spring, the amount of precipitation was 30%–60% of normal in some parts of the north and southeast, but up to 170% of normal in the west and northwest. Chahbahar station recorded 300% of normal precipitation. In total, spring 2010 was the only season this year in which average precipitation was above the long-term normal. During summer, most parts of the country received below-normal precipitation, although the northwest and some isolated areas elsewhere received above-normal precipitation. While the highest recorded summer precipitation was 323.7 mm in Bandar-Anzali, some widespread areas in different parts of the country (especially west and central areas) received no measured rainfall at all. During autumn, all parts of the country received less than 90% of their normal rainfall.

#### *(C) Notable events*

The potential for air pollution increased due to the extent of cold high pressure systems and stable air masses during October and November for many consecutive days, especially in metropolitan and industrial cities including the capital city of Tehran.

Significant dust storms during winter, spring, and summer spread over large parts of south and southwest Iran. Low-pressure systems with very low humidity accompanied by troughs over Iraq and Saudi Arabia and associated with increased wind speeds were the main cause of the dust storms. Eastern and southeastern Iran experienced dust as usual in spring and summer. However, the source of those typical events is completely different to that associated with the dust in the south and southwest.

In 2010, methane gas production from dried leaves, accompanied by low pressure systems over the north of the country, induced a number of forest fires in the Golestan, Mazandaran, and Gilan Provinces.

### *(iii) Turkey*—S. Sensoy and M. Demircan

#### *(A) Temperature*

The annual average temperature for Turkey (based on data from 130 stations) in 2010 was 15.54°C. The 2010 mean temperature was 1.95°C above the 1971–2000 average of 13.59°C. Generally, the whole country had temperatures above the mean, with highest anomalies occurring in eastern regions (Fig. 7.45). Positive temperature anomalies have been observed every year since 1994, apart from 1997. Monthly average temperatures during 2010 were above the 1971–2000 average during most months but were near normal in April and October. A negative correlation (-0.30) was found between the North Atlantic Oscillation (NAO) index and Turkey's winter temperature (Sensoy et al. 2010). The NAO was negative during all months of 2010.

#### *(B) Precipitation*

Rainfall in Turkey is affected by topography. For example, Rize (located in the eastern Black Sea region) receives an average of 2200 mm precipitation annually

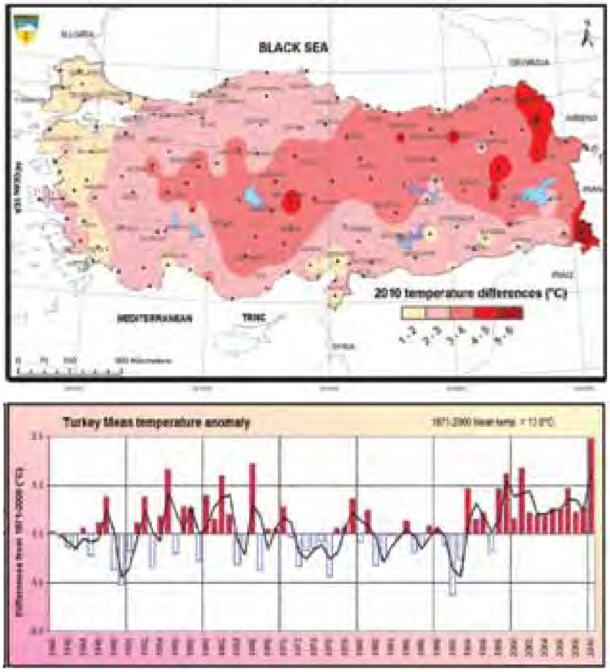


**Fig. 7.45. Temperature anomalies for 2010 in Turkey (°C). The top panel shows the spatial distribution of anomalies for 2010 while the bottom panel shows a time series of national average anomalies since 1940.**

while Konya (located in central Anatolia) receives an average of only 320 mm (Sensoy 2004).

Average annual total precipitation for Turkey as a whole is about 635 mm. In 2010, the annual rainfall was 729 mm (Fig. 7.46). Generally, western and northeastern parts of the country had precipitation above the mean total, except Southern Anatolia region where slightly-below-normal rainfalls were observed. Large positive anomalies occurred in Bursa, Balikesir, Edremit, and Yalova, with some rainfall events leading to hazardous floods in these cities. Bursa had its wettest year on record [1328 mm, 96% above normal (WMO 2010)].

Monthly precipitation totals were much above normal in January, February, June, October, and December, and below normal in March, April, May, August, and November. A negative relationship was found between Turkey's precipitation and the NAO index (0.50), which is particularly strong in winter and was negative throughout 2010. The NAO affects Turkey's climate more strongly than ENSO (Sensoy et al. 2010).

*(C) Notable events*

The highest number of extreme events in Turkey since 1940 was reported in 2010 (555 events). There is an increasing trend of 25 events decade$^{-1}$. The most frequent and hazardous extreme events are storms, floods, drought, and hail. During 2010, nearly half of the extreme event total was made up of storms (46%). Floods were the next most frequent extreme event in 2010 (29%), followed by hail (14%). Although rare, landslides, lightning, tornadoes, and avalanches are other disastrous extreme events that occur in Turkey.

On 13–14 October, 122.8 mm of rainfall was recorded in 24 hours in Bursa. For this amount of rain in 24 hours, the average return interval was estimated to be 200 years (WMO 2010). Similar heavy rainfall occurred again on 27 October. Both events resulted in many floods and landslides. There was one death, and several primary and secondary schools were suspended for two days.

In Rize, extreme rainfall was associated with floods and landslides on 26 August 2010. According to the disaster report, 13 people died, one person was missing, 168 houses were destroyed, and 1729 hectares of fields, roads, and water pipes were damaged. Total economic lost was estimated as 30 million Turkish Lira ($20 million U.S. dollars).

*h. Oceania*

(1) Southwest Pacific— A. Peltier and L. Tahani

Countries considered in this section include: American Samoa, Cook Islands, Fiji, French Poly-

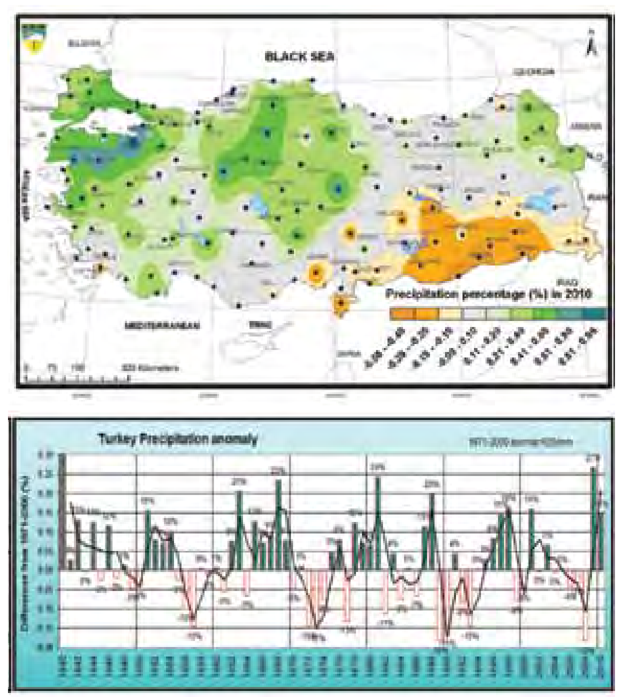


**Fig. 7.46. Annual total precipitation anomaly for 2010 across Turkey, expressed as a percent departure from the 1971–2000 normal. The top panel shows the spatial distribution of anomalies for 2010 while the bottom panel shows a time series of national average anomalies since 1940.**

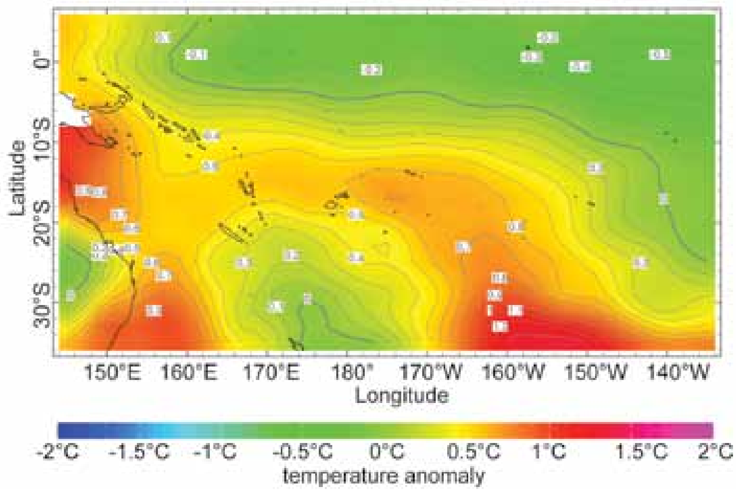


**Fig. 7.47. Annual surface air temperature anomalies (°C) for 2010 (1971–2000 base period) over the southwest Pacific from NOAA NCEP.**

nesia, Kiribati, Nauru, New Caledonia, Niue, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, and Vanuatu. Unless otherwise noted, temperature and precipitation anomalies are relative to a 1971–2000 base period. The year in the Southwest Pacific was strongly influenced by the transition from a moderate El Niño over the southern summer to a strong La Niña in the second half of the year (see section 4bf).

*(i) Temperature*

Above-average surface air temperatures, with anomalies mostly exceeding +1°C, were recorded at numerous stations in the equatorial Pacific as well in Wallis and Futuna, Samoa, and most of the French Polynesia during austral summer as a result of El Niño. In contrast, an extended area of cooler air (less than 0.5°C below average) encompassed the Solomon Islands, New Caledonia, southern islands of Vanuatu, Fiji, Tonga, Niue, Southern Cook Island, and Austral Islands. With the development of La Niña conditions around July, the temperature pattern reversed with well-below average temperatures restricted to the equatorial Pacific and relatively high air temperatures over most of the southwestern Pacific. On average, surface temperatures were above normal in 2010, since La Niña prevailed most of the year (Fig. 7.47).

*(ii) Precipitation*

Rainfall patterns over the southwestern (SW) Pacific are heavily influenced by ENSO fluctuations. As 2010 was dominated by two opposite phases of similar intensity, the overall rainfall anomaly was rather weak in most of the SW Pacific (Fig. 7.48). Exceptions were Marquesas, which had drier-than-average conditions (less than 60% of normal rainfall, compared to the 1979–95 base period), and Eastern Kiribati, where heavy rainfalls during the first two months contributed to a slight annual surplus (120% of normal). For most Pacific islands, the rainfall pattern observed in 2010 was fairly typical of El Niño conditions early in the year and representative of La Niña conditions during the second half.

During the first three months of 2010, the Intertropical Convergence Zone (ITCZ) was displaced towards the Equator (section 4f). Convection was then enhanced from west of Nauru across Western Kiribati to Eastern Kiribati, and suppressed over Papua New Guinea. On a smaller scale, the Madden Julian Oscillation (MJO) also contributed to intense precipitation along the Equator with the enhanced phase located across the western and central Pacific from late January to early February. Also consistent with El Niño, the South Pacific Convergence Zone (SPCZ) was shifted eastward during January–March, hence above-average precipitation occurred over the eastern edge of the Solomon archipelago, Tuvalu, Tokelau,

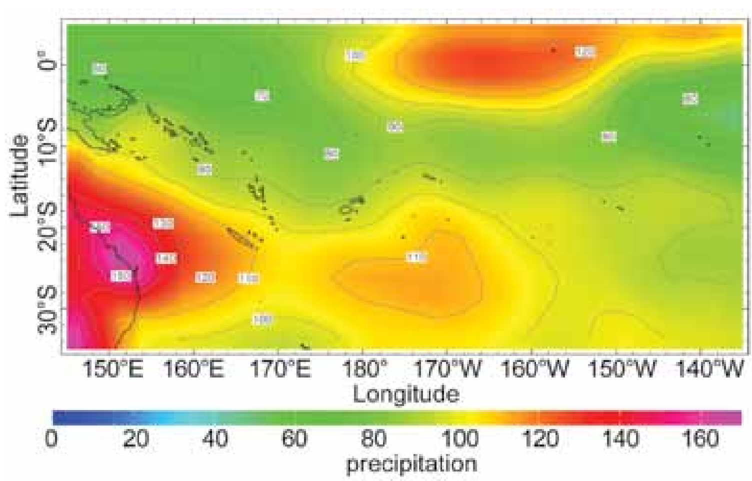


**Fig. 7.48. Percentage of average annual rainfall for 2010 (1979–95 base period) over the southwest Pacific from NOAA NCEP CPC CAMS_OPI v0208.**

Samoa, Northern Cook islands, and parts of French Polynesia (Society Islands, Tuamotu archipelago, and Gambier islands). Meanwhile, rather dry conditions persisted across New Caledonia, Vanuatu, Fiji, Tonga, Wallis and Futuna, Niue, and Southern Cook Island. These islands did not receive the water supply usually expected during austral summer.

Soon after the decay of El Niño during austral autumn, convection remained suppressed in the equatorial Pacific. As expected during La Niña conditions, mainly below-average rainfall was recorded each month from June to December 2010 in Nauru, Tuvalu, Tokelau, Kiribati, and Marquesas Islands. Heavy precipitation was confined to the very western edge of the equatorial Pacific. Parts of Papua New Guinea and Solomon Islands were affected by a rather contracted SPCZ during austral winter.

In the islands farther south, La Niña effects became apparent during the last quarter of 2010. As the SPCZ was displaced southwest of its normal position, above-average rainfall was recorded in New Caledonia, Vanuatu, Fiji, Tonga, Niue and the Southern Cook Islands, and Austral Islands, whereas precipitation was less abundant over the rest of French Polynesia and the Northern Cook Islands. Over Wallis and Futuna, as well as Samoa, precipitation amounts were near normal during late 2010.

*(iii) Notable events*

Fourteen synoptic-scale low pressure systems formed in the Southwest Pacific in 2010, seven of them intensifying into tropical cyclones within the SW Pacific basin. Tropical cyclone (TC) activity was prominent during the first quarter of 2010; a single storm developed during the end of year. Because of the El Niño conditions, cyclonic activity was shifted easterly towards the center of the Pacific during the 2009/10 season. Also typical of El Niño, the mean genesis location was displaced towards the Equator.

Tropical Cyclone Oli originated near the Tuvalu archipelago and started its 5000 km-long journey through the southwest Pacific on 29 January. As it moved southeastward, the tropical depression intensified progressively and reached Category 4 status as it passed 300 km west of Society Islands on 3 February. There, hundreds of families coped with damages caused by wind and wind-waves of up to seven meters. The storm's trajectory then turned south toward the Austral Islands. The eye of Oli passed over Tubuai on 5 February, with a minimum sea level pressure of 955.8 hPa and sustained winds of 55 kts (28 m $s^{-1}$) with gusts up to 92 kts (47 m $s^{-1}$). Along the northern and northeastern coasts 145 homes were completely shattered by winds and flooding sea water. Oli became the second most intense tropical cyclone recorded in French Polynesia. (The most violent was Orama in 1983 with a minimal pressure recorded at 870 hPa.)

Cyclone Tomas formed in the vicinity of Tokelau on 7 March, moved west, then south and threatened at first Wallis and Futuna archipelago. On 17 March it passed within 100 km of Futuna while a Category 2–3. No casualties were reported but severe damage to coastal areas, crops (80% destroyed), and infrastructure occurred on Futuna. Most traditional "fales" were damaged or destroyed because of wind action and storm surge. Unfortunately, the semi-automatic weather station ran out of battery power early on the 17th and therefore no maximum wind speed were recorded at Futuna's synoptic station. Maximum wind speed was nonetheless estimated at 92 kts (47 m $s^{-1}$), probably the highest value since 1979. With estimated winds near the center gusting up to 135 kts (69 m $s^{-1}$), Tomas reached its peak intensity near Vanua Levu (Fiji) while it moved southward. Five thousand people were evacuated in the island's Northern division. Many coastal villagers in this area had their food crops ruined for months because of salt intrusion into the soil (see section 4d6 for more information on the southwest Pacific hurricane season).

### (2) Northwest Pacific, Micronesia—C. Guard and M. A. Lander

*(i) Overview*

This assessment covers the area from the International Date Line west to 130°E, between the Equator and 20°N. It includes the U.S.-affiliated islands of Micronesia, but excludes specific discussions concerning the western islands of Kiribati and the Republic of Nauru. In this Pacific region, the regional climate is strongly influenced by the phase and phase changes of ENSO (section 4b).

Temperature, rainfall, sea level, tropical cyclone distribution, and most other climate variables roughly corresponded to the behavior that would be expected in a year that began as El Niño and then transitioned rather rapidly to a La Niña event. Such years tend to be warm and dry across Micronesia. During the first half of 2010, Micronesia experienced enhanced easterly trade winds, strong subsidence, and dry weather, typical of a post-El Niño year. The mid-year transition to La Niña conditions further enhanced the trade winds, shifting monsoon trough activity and tropical cyclone (TC) development far to the north and west of normal. As a result, Micronesia experienced one of its least active TC seasons on record. Tropical cyclone activity across the whole North Pacific basin was far below normal (50%) and set new historical record lows (see section 4d4).

*(ii) Temperature*

Average monthly maximum temperatures (maxT) and minimum temperatures (minT) across most of Micronesia have been rising for several decades at a rate that exceeds the reported rise of global average temperature of +0.74°C in the last century. The temperature time series at Guam's Andersen Air Force Base (AAFB) is typical (Fig. 7.49).

The anomalies of maxT and minT across Micronesia during the first and second half of 2010 (Table 7.4) were mostly above normal. However, the minT at two stations, Yap and Pohnpei, has shown a long-term decrease. In keeping with this trend, the minT at Pohnpei was below normal in both halves of 2010, but the minT at Yap during the first and second half of 2010 was +2.08°C and +2.07°C above normal, respectively. While minTs from January through June were expected to be cooler than normal, they were in fact, considerably warmer than normal at several locations, possibly as a result of the higher than normal sea surface temperatures (SSTs) across much of the region.

**Table 7.4. Maximum and minimum temperature anomalies and rainfall anomalies for selected Micronesian locations for January through June 2010 (Jan–Jun) and for July through December 2010 (Jul–Dec). Maximum and minimum temperature anomalies are in degrees Celsius per month (°C mo$^{-1}$) for the indicated periods and rainfall anomalies are in millimeters (mm) for the indicated periods. "N" is the normal rainfall taken from the NCDC 1971–2000 base period. Locations (latitude and longitude) are approximate. NA indicates that the temperature normals are not available from NCDC. Kapinga stands for Kapingamarangi Atoll in Pohnpei State, Federated States of Micronesia (FSM).**

| Location | Max Temp<br>Min Temp | | Rainfall | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Jan–Jun | Jul-Dec | Jan–Jun | | | Jul–Dec | | | Jan-Dec | |
| | °C mo$^{-1}$ | °C mo$^{-1}$ | N mm | 2010 mm | % | N mm | 2010 mm | % | 2010 mm | % |
| Saipan<br>15°N,146°E | NA | NA | 414.8 | 342.4 | 82.5 | 1293.1 | 1036.8 | 80.2 | 1379.2 | 80.8 |
| Guam<br>13°N,145°E | +0.29<br>+0.52 | -0.07<br>+0.28 | 612.1 | 466.9 | 76.3 | 1555.5 | 1484.1 | 95.4 | 1951.0 | 90.0 |
| Yap<br>9°N,138°E | -+0.75<br>+2.08 | +1.12<br>+2.07 | 1168.9 | 804.9 | 68.9 | 1818.6 | 1957.8 | 107.7 | 2762.8 | 92.5 |
| Palau<br>7°N,134°E | +0.04<br>-0.22 | -0.07<br>+0.39 | 1724.7 | 1030.7 | 59.8 | 2043.9 | 1676.9 | 82.0 | 2707.6 | 71.8 |
| Chuuk<br>7°N,152°E | +0.63<br>+1.33 | -0.31<br>+1.23 | 1538.0 | 1553.0 | 101.0 | 1864.9 | 2093.2 | 112.2 | 3646.2 | 107.2 |
| Pohnpei<br>7°N,158°E | +0.35<br>-0.82 | +0.10<br>-0.10 | 2277.6 | 2122.9 | 91.6 | 2411.5 | 2068.8 | 85.1 | 4191.8 | 88.3 |
| Kapinga<br>1°N,155°E | NA<br>NA | NA<br>NA | 1670.8 | 1956.1 | 117.1 | 1123.7 | 312.9 | 27.8 | 2269.0 | 81.2 |
| Kosrae<br>5°N,163°E | +0.57<br>+1.66 | -0.47<br>+0.56 | 2387.3 | 20.93.2 | 79.5 | 2128.8 | 1845.8 | 78.2 | 3939.0 | 78.9 |
| Majuro<br>7°N,171°E | +0.57<br>+1.91 | -0.18<br>+1.08 | 1455.4 | 1517.1 | 104.2 | 1888.7 | 2337.3 | 123.8 | 3854.5 | 115.3 |
| Kwajalein<br>9°N,168°E | +0.43<br>+0.80 | 0.00<br>+0.14 | 959.6 | 660.2 | 68.8 | 1590.5 | 1557.3 | 97.9 | 2217.4 | 87.0 |

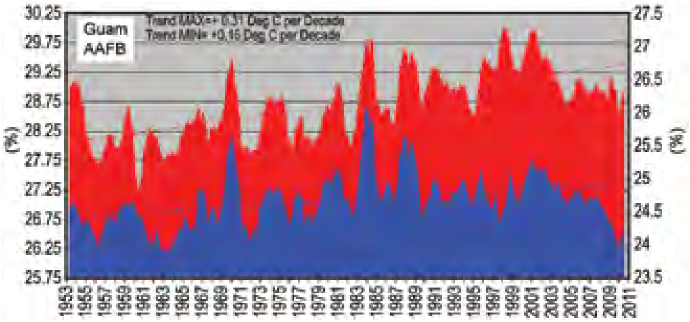


**Fig. 7.49. Time series of MaxT (red) and MinT (blue) at Andersen Air Force Base, Guam. Values are 12-month moving average of the monthly averages. General features of this time series are: a substantial warming trend, a peak of MaxT and MinT in the late 1990s, and recent cooling during the 2000s.**

Sea surface temperatures around Chuuk and Yap were 1°C–2°C warmer than normal, and this may have influenced their rather large respective average minT anomalies of +1.66°C and +2.08°C. Farther east, Pohnpei experienced January–June maxT anomalies of +0.35°C and minT anomalies of -0.82°C. Still farther east, anomalies at Kosrae were larger (maxT +0.57°C for January–June), as a result of clearer weather and higher SSTs. At the eastern end of the region, Majuro had warmer-than-normal January–June average maxT anomalies of +0.57°C and minT anomalies of +1.91°C. Farther north at Kwajalein, average maxT (+0.43°C) and minT (+0.80°C) anomalies for the first six-month period were both warmer than normal, but not as warm as at Majuro.

Temperatures for July–December were closer to normal than those during the first half of the year at most locations. As in the first half of the year, Yap showed the greatest anomalies with a maxT of +1.12°C and a minT of +2.07°C. MaxT and minT anomalies were small for the last six months of the year at Pohnpei, Kwajalein, and Guam. MaxT and minT anomalies at Chuuk (-0.31°C and +1.23°C), Kosrae (-0.47°C and +0.56°C), and Majuro (-0.18°C and +1.08°C) were larger than normal, especially the minT values.

*(iii) Precipitation*

Precipitation was typical for a year that begins with El Niño conditions and ends with La Niña conditions. In the first half of the year, the western half of the basin and islands north of 8°N were drier than normal, while most of the islands east of 150°E were either drier than normal or near normal. Palau's rainfall for the first six months was only 59.8% of normal, while Yap was 68.9%, and the rainfall amounts at Guam and Saipan in the Mariana Islands were 76.3% and 82.5% of normal, respectively. Conditions at Kwajalein and Kosrae were also dry with 68.8% and 79.5% of normal rainfall, respectively. Several islands (Chuuk, Pohnpei, and Majuro) experienced near normal rainfall.

During the last half of the year, most locations saw a 20%–30% increase in rainfall over the first half of the year as El Niño gave way to La Niña. From west to east across Micronesia, Palau rainfall increased to 82.0% above normal (a 22.2% increase from the January–June average); Yap rainfall increased to 107.7% (+38.8%); Chuuk increased to 112.2% (+11.2%); Majuro to 123.8% (+19.6%); Kwajalien to 97.9% (+29.1%); and Guam to 95.4% (+19.1%). Rainfall at Pohnpei and Kosrae were less than expected, partly as a result of the unusually far westward and northward extent of the equatorial wedge of cold SSTs and its effect on the trade wind trough.

A major exception to the Micronesian rainfall pattern was at the near-equatorial location of Kapingamarangi Atoll (1°N, 155°E) in Pohnpei State of the Federated States of Micronesia, where it was wetter than normal (117%) during the first half of the year in response to the El Niño-induced equatorial warm SSTs. Once the La Niña pattern set in, warm equatorial SSTs were replaced by a cool tongue of SSTs, and conditions at Kapingamarangi became very dry (27.8% of normal) through the end of 2010 and into 2011. The Weather Forecast Office in Guam issued weekly Drought Information Statements for the Atoll from August 2010 well into 2011.

For the most part throughout Micronesia, rainfall for the first and second halves of 2010 was between 75% and 125% of average. Of the major islands, annual rainfall amounts ranged from a high of 4191.8 mm at Pohnpei (88.3% of normal) to a low of 1379.2 mm at Saipan in the U.S. Commonwealth of the Northern Mariana Islands (80.8% of normal). Palau at the western edge of the area was also dry with 2707.6 mm (71.8% of normal), while Majuro at the eastern edge of the area was wet with 3854.5 mm (115.3% of normal). The six-month and annual rainfall values for selected locations are summarized in Table 7.4. Figure 7.50 shows the annual rainfall amount and percent of normal for the major Micronesian islands.

*(iv) Notable events*

Tropical cyclone activity in 2010 was at record low levels in the western North Pacific (see section 4d4) and it was virtually non-existent across Micronesia. Only two tropical cyclones developed in Micronesia, and both were in the northwest part of the region.

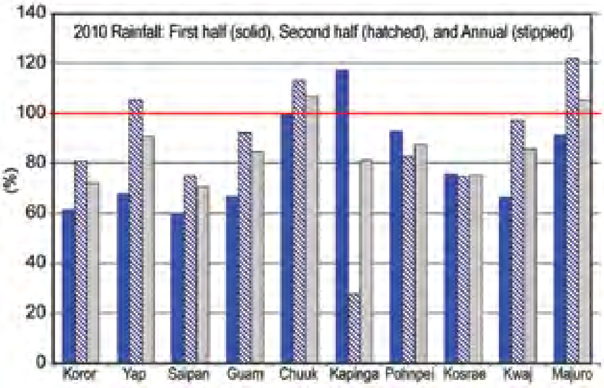


**Fig. 7.50. Annual rainfall as a percentage of normal (NCDC 1971–2000 base period) for selected locations on various Micronesian islands for 2010. Kapinga stands for Kapingamarangi Atoll in Pohnpei State, Federated States of Micronesia (FSM).**

Neither intensified significantly until after moving west of 130°E longitude and neither tropical cyclone affected populated locations of Micronesia.

The high sea levels that prevailed in 2007 to early 2009 began to fall by mid-2009 as El Niño conditions reduced the easterly wind stress that caused water to mound up in the west of the basin. The development of oceanic Kelvin waves also caused much of the heat content in the upper 300 meters of the ocean to be transported eastward toward Central and South America, reducing ocean volume in the equatorial western Pacific and causing sea levels to fall. This fall in sea level reduced the incidence of destructive coastal inundation events in the Micronesian islands during the latter half of 2009 and early 2010. After La Niña became re-established, the strengthening trade winds increased the easterly wind stress, and once again, water began to mound up in the west of the basin. This caused warm water to mix downward, increasing the oceanic volume and causing sea levels to further rise by the last three months of the year.

After the El Niño peaked in late 2009, sea levels in Micronesia reached their lowest levels around February 2010. The lowest anomalies (compared to the 1975–95 average) occurred in the west at Palau (-16 cm) and Yap (-12 cm) and diminished eastward at Chuuk and Pohnpei to around 0 cm. At some locations, sea level anomalies remained positive, such as at Marshall Island locations where the lowest anomalies were +5 cm, and at Guam (+6 cm). The sea level in Micronesia increased from boreal spring and grew most rapidly towards the end of the year, reaching their highest values in November and December. Average anomalies ranged from +18 cm to +20 cm at Palau, Yap, Chuuk and Guam to +23 cm at Pohnpei. Positive sea level anomalies occurred despite the reduced ocean volume (and reduced sea level) resulting from the cooler-than-normal equatorial SSTs.

### 3) Australia— C. Ganter and S. Tobin

#### *(i) Overview*

Australia experienced its second wettest year on record in 2010. As is typical during strong La Niña events, 2010 brought with it significant flooding, especially in the eastern states. The year was the wettest on record for Queensland and the Murray-Darling Basin, third-wettest for the Northern Territory, New South Wales, and South Australia, and fifth-wettest for Victoria. In stark contrast, southwest Western Australia had its driest year, austral winter (June–August), and growing season (April–October) on record, while Tasmania received near-average rainfall. Unless otherwise noted, anomalies in this section are relative to a 1961–90 base period.

#### *(ii) Temperature*

Despite widespread rainfall and increased cloudiness, the national mean temperature for 2010 remained above average (22.0°C, +0.19°C above average). Although this was Australia's coolest year since 2001, the last decade (2001–10) was the warmest 10-year period on record (0.52°C above average). In 2010, overnight minimum temperatures (Fig. 7.51) were the eighth highest on record (0.59°C above average). Mean maximum temperatures (Fig. 7.52) were 0.21°C below average.

Annual maximum temperature anomalies exceeded +0.5°C across most of Western Australia, the far north, and Tasmania. Cool anomalies below -0.5°C were recorded across much of inland New South Wales, Queensland, South Australia, and the Northern Territory. The warmest anomalies were in the west of Western Australia (+1.5°C) and the coolest in the southeastern Northern Territory ( 2.5°C).

Annual minimum temperatures were above average through most of Australia, especially along the northern coasts, in part due to record high sea surface temperatures. Minimum temperature anomalies exceeded +2.0°C in parts of the Northern Territory and inland of Cairns in Queensland. Below-average minima occurred in southwest Western Australia, around Port Augusta in South Australia, and through areas of interior Australia. The largest negative anomalies (-0.5°C) were in western Queensland.

The largest positive maximum temperature anomalies occurred in February; +5.0°C in areas of the Pilbara and Gascoyne in Western Australia.

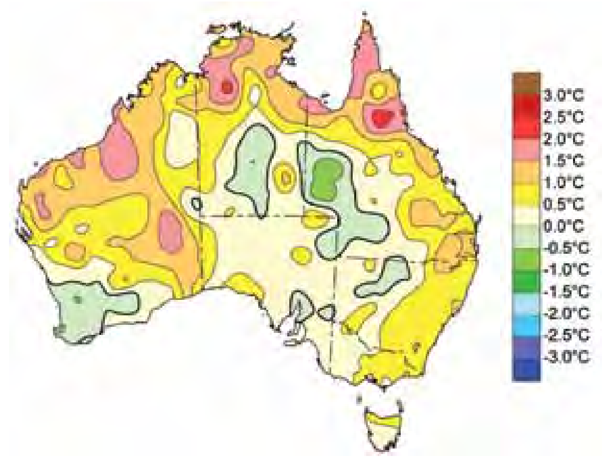


**Fig. 7.51. Australian mean annual minimum temperature anomalies (base period of 1961–90) for 2010.**

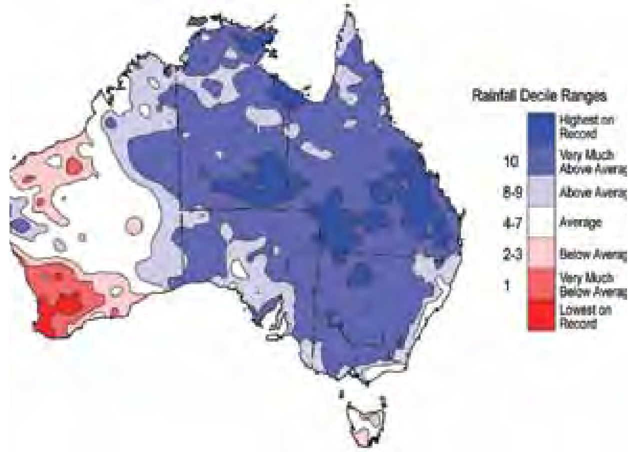


**Fig. 7.53. Australian annual rainfall deciles (since1900) for 2010.**

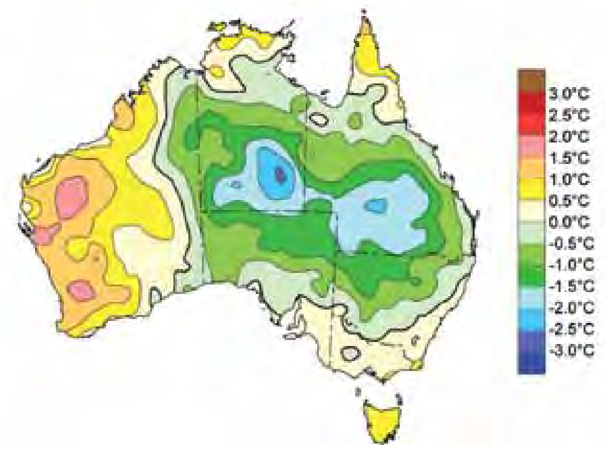


**Fig. 7.52. Australian mean annual maximum temperature anomalies (base period of 1961–90) for 2010.**

April temperatures were above normal, particularly in the west. The Australia-wide, area-averaged April anomaly (+1.68°C) was the second highest on record.

The tropics were particularly warm for July–September, with widespread areas of record high means and minima. The largest positive anomalies were recorded for July, with minima 4°C–6°C higher than usual across large parts of northern Australia. Below-average maxima covered most of the remainder of Australia in September, and most of Australia, except the far west, in October; anomalies of -4.0°C in central Australia were associated with record high rainfall in the region.

Below-average temperatures were most widely recorded in November; maxima were more than 5°C below average across a large area of inland Queensland, while minima were more than 3°C below average in a large area of central Australia.

*(iii) Precipitation*

Australia's mean annual rainfall for 2010 was 701 mm, 51% above average (465 mm) and second highest since records began in 1900. Above-average rainfall was recorded in all months except June. Rainfall was significantly above average in all states except Tasmania and Western Australia (Fig. 7.53). Record totals fell across southern Queensland, parts of central Australia and the far north, New South Wales, Victoria, and South Australia. Southwest Western Australia had its driest year on record—395 mm, well below the previous low of 439 mm set in 1940.

For parts of the southeast, particularly Victoria and South Australia, 2010 was the first year of above-average rainfall since 1996. Similarly, 2010 marked a reversal of dry conditions which had dominated since 2001 across Queensland and New South Wales, including much of the nation's food basket in the Murray-Darling Basin. Areas along the eastern coast of New South Wales and south of the Great Dividing Range in Victoria, where relationships between La Niña and rainfall are weaker, received near-average rainfall.

January–March rainfall was generally above average, especially in northern Queensland and the Northern Territory during January, and across the central interior and east during February and March. However, it was dry in the west of Western Australia, where Perth Airport experienced a record 122 consecutive rainless days between 20 November 2009 and 22 March 2010.

April and May saw above-average rain in much of Australia (except for the east coast and west of Western Australia), including record falls around the Gulf of Carpentaria and central South Australia in April, and in the northwest in May. June rainfall Australia-wide was the fourth-lowest on record, and was the only month in which the tropics saw consistently dry conditions typical of the season.

Record-breaking rain fell in the interior and northwest in July; in northern, central, and eastern Australia in August; throughout northern and central Australia and western New South Wales in October; and was exceptionally widespread in September. November and December saw very-much-above-average rainfall in Queensland, New South Wales, Victoria, and eastern South Australia. Record-breaking December rain fell in southeast Queensland and in a large area of Western Australia around Carnarvon. Averaged over Australia, austral spring (September–November), the July–December period, and December were the wettest on record.

*(iv) Notable events*

The most notable aspect of Australia's climate during 2010 was the numerous flooding events resulting from the La Niña event (see Sidebar 7.9).

Early in the year, there were two occurrences of severe thunderstorms producing damaging large hailstones. The first, which occurred in Melbourne on 6 March, produced heavy rain, strong wind gusts, and hailstones over 5 cm in diameter across a large area of Melbourne's suburbs, including a 10-cm hailstone, a record for the Melbourne region. There was also widespread severe thunderstorm activity from 5 to 7 March across central and north central Victoria, stretching into southern New South Wales. The second notable occurrence of severe thunderstorms occurred on 22 March in Perth, producing heavy rain, severe winds, and large hail, including a 6-cm hailstone in the northwest suburbs, a record for Perth. Both storms caused insured losses exceeding $1 billion (U.S. dollars).

The northern tropics of Australia experienced very warm temperatures, particularly minima, through winter, with coastal areas and islands strongly influenced by abnormally high sea surface temperatures. On 26 July, Cape Don in the Northern Territory set an Australian record high minimum for July with 26.9°C. Darwin (26.6°C) also broke the previous record. Timber Creek and Bradshaw (both 37.5°C on 30 July) set a new July maximum record for the Northern Territory, just 0.1°C short of the Australian record. Richmond recorded a maximum of 36.1°C on the same day, a Queensland record. In August, Horn Island and Coconut Island in the Torres Strait broke the previous Queensland record high minimum temperature for the month, 25.4°C, on no fewer than 24 separate occasions between them, with 26.8°C at Horn Island, on 19 August, the new record.

While northern Australia was very warm during the 2010 austral winter (JJA), southern Western Australia had persistently low minimum temperatures during late June and early July, associated with unusually dry conditions. Norseman Aerodrome (on the western Nullarbor) recorded a minimum of 6.0°C on 27 June, equaling the Western Australian June record.

Four tropical cyclones made landfall in Australia in 2010, Olga, Paul, Tasha, and Ului. Wind damage was generally minor but all contributed to flooding.

*Significant statistics*

- Mean annual maximum temperature anomaly: −0.21°C
- Mean annual minimum temperature anomaly: +0.59°C
- Mean annual rainfall anomaly: +51% (second highest of 111-year record)
- Highest annual mean temperature: 29.6°C, Wyndham (Western Australia)
- Lowest annual mean temperature: 4.3°C, Thredbo (New South Wales)
- Highest annual total rainfall: 12 438 mm, Bellenden Ker Top Station (Queensland) – second highest on record (record 12 461 mm, set in 2000 at the same station)
- Highest temperature: 49.2°C, Onslow (Western Australia), 1 January
- Lowest temperature: −19.6°C, Charlotte Pass (New South Wales), 20 July – second lowest on record (record −23.0°C, set on 29 June 1994 at the same station)
- Highest one-day rainfall: 443 mm, Bulman (Northern Territory), 31 March
- Highest wind speed (measured): 202 km $hr^{-1}$, Hamilton Island (Queensland), 21 March

4) New Zealand—G. M. Griffiths

*(i) Overview*

Annual mean sea level pressures were above average in the New Zealand region in 2010. The increased prevalence of anticyclones near New Zealand produced a relatively settled and mild climate for the year overall, with average or above-average annual temperatures in all regions, and normal or above-normal annual sunshine hours in most regions. There were relatively few rainfall extremes. The Southern Annular Mode (SAM), which affects the westerly

## SIDEBAR 7.9: AUSTRALIA, A LAND OF (DROUGHT AND) FLOODING RAINS—C. GANTER AND S. TOBIN

Note: Many Australians, and visitors to Australia, will be familiar with Dorothea Mackellar's iconic poem "My Country". First published in 1908, the poem describes the breaking of a drought, highlighting the contrast and extremes found within the Australian landscape and climate. The well-known second stanza, from which the title of this box is derived, is given below-

***I love a sunburnt country,***
***A land of sweeping plains,***
***Of ragged mountain ranges,***
***Of droughts and flooding rains.***
***I love her far horizons, I love her jewel-sea,***
***Her beauty and her terror -***
***The wide brown land for me!***

Australia experienced flooding across many regions during 2010. Much of the flooding occurred in the second half of the year, during the strong La Niña event in the Pacific. In addition, record high tropical sea surface temperatures near Australia for 2010, partly associated with La Niña, fed extra moisture into the region. The flooding events listed here are the most significant for 2010, but by no means represent an exhaustive list.

The first major flooding for the year occurred in late February and early March. A monsoon low passed over the Northern Territory and into southern Queensland, continuing through northern New South Wales. This system produced heavy rainfall in its path, resulting in widespread, and in places record-breaking, flooding. Major flooding occurred in most of the catchments in southern inland Queensland, and some of these areas had their highest river peak on record. The rainfall on 2 March 2010 was Queensland's wettest day on record (area-average of 32 mm) and daily falls exceeded 100 mm over 1.9% of the country (a record), indicating the wide extent of the heavy rains. This event also brought significant flooding downstream in northwest New South Wales, with some areas remaining affected by flood waters well into April.

The second major flooding event occurred during September in northern Victoria. A complex low pressure system moved over Victoria on 3–4 September, producing widespread heavy rainfall along and north of the Divide. Some locations in northern Victoria had new record flood peaks as a result of this event. There were further floods on various rivers in northern Victoria and southern New South Wales over the following weeks. Although these were generally less significant, an event in mid-October caused substantial damage in parts of the Riverina region of New South Wales.

The Gascoyne region, located along the central coast of Western Australia, stretching inland, experienced one of the most extreme rainfall events in 2010. A monsoon low passed over the region during mid-December, producing heavy falls and flooding. Carnarvon Airport recorded 207.8 mm on 17 December, almost tripling its annual rainfall total to date in one day and far surpassing its previous daily record of 102.6 mm on 13 July 1998. Historically, rainfall events during December in this region are rare. Besides a single daily total of 77 mm during 1995, prior to this event Carnarvon Airport hadn't recorded a December total above 6 mm in its 66 years of record.

The final major flooding event of 2010 continued through the last weeks of the year, and was the result of four rain events affecting eastern Australia between late November through to the end of December (flooding continued into early 2011). These rain events were mostly the result of persistent inland troughs over eastern Australia; however one was the result of a combination of moist easterly flow over Queensland, with further moisture brought in by the circulation associated with Tropical Cyclone Tasha. The most severe flooding occurred in Queensland and far northern and central western New South Wales during the last week of December, with downstream impacts continuing into January 2011. These events resulted in the wettest December on record for Queensland and eastern Australia as a whole (includes Queensland, New South Wales, Victoria and Tasmania). See Fig. 7.54 for Australian December rainfall deciles[3] .

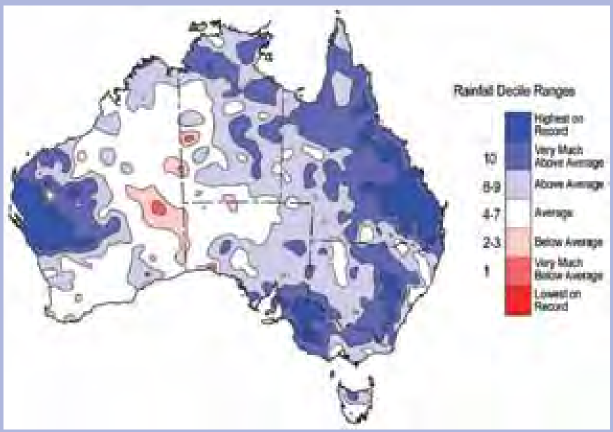


**Fig. 7.54. Australian rainfall deciles for December 2010.**

[3]Australian rainfall deciles based on a 111-year climatology of gridded fields from 1910 to 2010. Decile range 1 means the lowest 10% of records, decile range 2 the next lowest 10% of records,..., decile 10 the highest 10% of records.

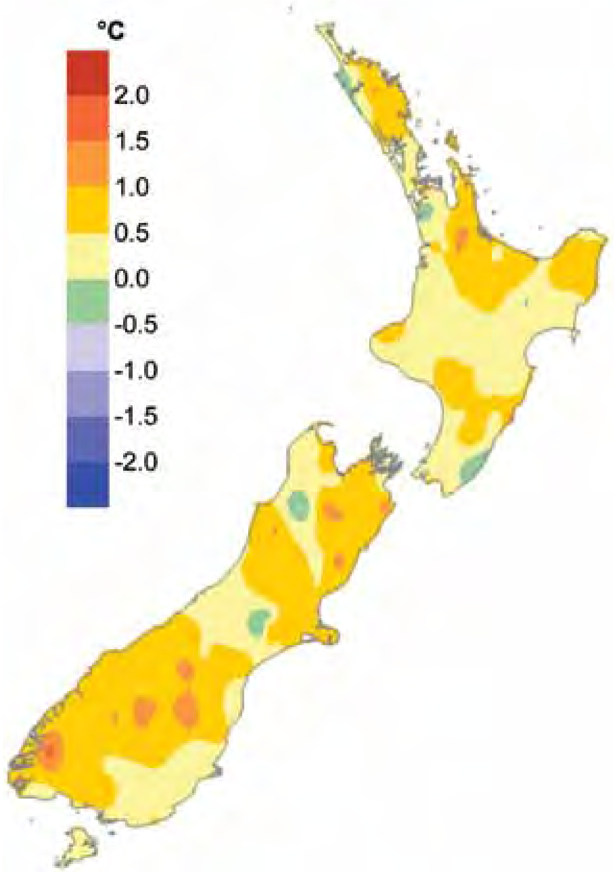


**Fig. 7.55. New Zealand annual mean temperature anomaly (°C) for 2010 relative to 1971–2000 average.**

wind strength and location over and to the south of New Zealand, was strongly positive overall in 2010, and contributed to the prevalence of anticyclones experienced over the country. In the following discussion, the base period is 1971–2000 for all variables. The New Zealand national temperature is based upon a seven-station record found at http://www.niwa.co.nz/our-science/climate/news/all/nz-temp-record/seven-station-series-temperature-data.

*(ii) Temperature*

Mean annual temperatures (Fig. 7.55) were above average (between 0.5°C and 1.2°C above the long-term average) in the northeast of the North Island and for much of the South Island (Nelson, Marlborough, parts of Canterbury, Fiordland, parts of Westland, the southern Lakes District, and central Otago). Mean annual temperatures were near average elsewhere (within 0.5°C of the long-term average). The national average temperature for 2010 based on a seven-station series was 13.1°C, 0.5°C above the 1971–2000 annual average. The year 2010 was the fifth warmest year since 1900, based on this seven-station series.

Of the 12 months of 2010, seven (February, April, May, August, September, November, and December) were warmer than normal, one (October) was cooler than normal, and four (January, March, June, and July) were near normal. The largest positive anomalies were in the northeast of the North Island (Northland, Auckland, and Bay of Plenty), in the northeast of the South Island (Marlborough and north Canterbury), and in Fiordland and central Otago.

*(iii) Precipitation*

Annual rainfall totals for 2010 were in the near-normal range (80%–119% of normal) across most of New Zealand. The exceptions were eastern parts of the North Island (specifically Coromandel, parts of the Bay of Plenty, Gisborne, Hawke's Bay, and Wairarapa), Blenheim, parts of North Canterbury, and southwest Fiordland, which experienced above normal annual rainfall (with totals greater than or equal to 120% of normal). In contrast, areas of Northland, Auckland and Waikato, Otago, the Lakes District, and parts of the West Coast and Buller recorded below normal annual rainfall totals (between 50% and 79% of normal).

Dry conditions predominated in many areas during February–April, July, and in October–November. The year began and ended with very large soil moisture deficits and drought conditions in several North Island regions, and in parts of the east of the South Island. January, May, August, and September saw predominantly wet conditions in many regions. There was also significant rainfall in the last week of December, affecting mostly western regions and the Nelson/Marlborough area (northern South Island). The highest recorded rainfall for the year was at Cropp River in the Southern Alps (12 374 mm), while the lowest recorded rainfall total was 345 mm at Alexandra in Central Otago.

*(iv) Notable Events*

Notable climate features of 2010 (in various parts of the country) included two droughts, several heat waves, and four significant rainfall events. Drought was declared in January in Northland, and in Auckland, Waikato, Bay of Plenty, South Taranaki, South Canterbury, and Otago during April. The drought broke in May, only to be declared again in December in Northland, Waikato, and the Ruapehu District.

Heat waves affected the West Coast at the end of January, Central Otago on 8–9 March, and numerous locations on 28–30 November, 12–15 December, 22 December, and 27 December. Many all-time station maximum temperature records were set during these events.

Exceptionally heavy rain occurred on 31 January in the northeast North Island. Widespread heavy rain and flooding occurred in the southwest South Island from 25–27 April, resulting in flood-threshold levels of Lake Wakatipu; and a sustained period of heavy rain during 24–30 May in the eastern South Island caused numerous floods, slips, road and property damage. On 28 December, heavy rain, flooding, and high winds caused havoc for many areas of the country.

An extremely significant snowfall event occurred during 15–23 September, with heavy snowfalls, high winds, and extremely cold conditions observed in the southwest of the South Island. On 18 September, conditions were particularly extreme, causing the roof of Stadium Southland in Invercargill to collapse due to snow. Other parts of Southland were also affected, meaning milk was unable to be collected because of dangerous roads, and thousands of lambs were lost across the region.

*Significant statistics*

- The highest annual mean temperature for 2010 was 16.5°C, recorded at Whangaparaoa (Auckland).
- The lowest annual mean temperature (not including remote alpine sites) for 2010 was 8.0°C, recorded at Chateau Ruapehu (central North Island).
- Of the regularly reporting gauges, Cropp River in the Hokitika River catchment (West Coast) recorded the highest annual rainfall total of 2010, with 12 374 mm.
- The driest of the regularly reporting locations was Alexandra (Central Otago), which recorded 345 mm of rainfall in 2010.
- Milford Sound experienced the highest 1-day rainfall in 2010 (314 mm), recorded on 25 April.
- The highest recorded air temperature in 2010 was 35.6°C, observed at Cheviot on 22 February.
- The lowest recorded air temperature for 2010 was -12.6 °C, recorded at Lake Tekapo on 10 August.
- The highest recorded wind gust for 2010 was 217 km $hr^{-1}$ at Baring Head, Wellington, on 12 March (a new all-time record there).