7. REGIONAL CLIMATES

a. Introduction—A. B. Watkins and L. A. Vincent

This chapter provides a regional perspective of the global climate in 2009, with a focus on extreme or unusual events. Analyses are provided for continents, nations and most broad geographic regions. Where possible, information for the year is placed into a historical context using anomalies, percentages (relative to 1961-90, unless otherwise noted) or rankings. Authors for most regions are local scientists and hence, unless otherwise noted, data is made available by their affiliated agency. While this chapter covers the climate of 2009, information from the previous year may be included in order to accurately cover relevant climate events (e.g., descriptions of the austral summer and boreal winter seasons typically include data from December 2008).

Extreme warmth was experienced across large areas of South America, southern Asia, Australia and New Zealand, while severe cold snaps were reported in the United Kingdom, China and the Russian Federation. Drought affected large parts of southern North America, the Caribbean, South America and Asia while heavy rainfall and floods impacted Canada, the United States, Amazonia and southern South America, many countries along the east and west coasts of Africa, and the United Kingdom.

Descriptions of the background atmospheric state to local anomalies are found in Chapter 2. Similarly, descriptions of tropical cyclones may be found in Chapter 4. Seasonal summaries of temperature and precipitation are found in Chapter 8, and a global summary map is provided in Fig. 1.1.

b. North America

1) Canada—R. Whitewood and D. Phillips

The year 2009 was another warm year in Canada (relative to 1951–80). It was also a drier-than-normal year after experiencing seven consecutive wet years.

(i) Temperature

The national mean temperature for 2009 was 0.8°C above normal (Fig. 7.1), which ties 1988 as the fourteenth warmest year since nationwide records began in 1948. The warmest year was 1998 (+2.5°C), and 1972 (-1.8°C) remains the coolest. Much of Canada's above-normal temperatures occurred in the North, where temperatures were more than 2°C above normal (Fig. 7.2a). Overall, the rest of the country saw normal temperatures with the exception of southern Saskatchewan which experienced temperatures that were more than 1°C cooler than normal. The national annual mean temperature shows a linear increase of 1.4°C over the 62-year period (Fig. 7.1).

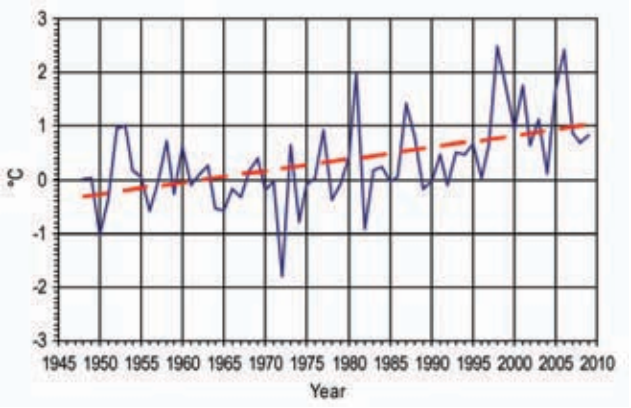


Fig. 7.1. Annual mean temperature anomalies for Canada, 1948–2009. The reference period is 1951–80. (Source: Environment Canada.)

In comparing the decades, it is clear that the 2000s was the warmest decade out of the six that are available for this national study, with an average temperature of 1.1°C above normal. In order, from warmest to coolest, the remaining decades are: 1990s (+0.7°C); 1980s (+0.4°C); 1950s (+0.1°C); 1960s (0.0°C); and 1970s (-0.2°C).

Seasonally, three of the four seasons were warmer than normal. Winter was 0.3°C above normal (33rd warmest); spring was 0.4°C cooler than normal (14th coolest); summer was 0.4°C above normal (27th warmest); and autumn experienced the greatest above normal temperatures of the four seasons, 1.7°C above normal (third warmest autumn on record).

(ii) Precipitation

Overall, Canada experienced a drier-than-normal year in 2009 (2.6% below normal) and it ranked as the 10th driest year out of the 62-year period of record. Fig. 7.2b shows the south experienced most of the dry conditions. Regions that were more than 20% drier than normal were: British Columbia's west coast, eastern British Columbia, most of Alberta, small regions of Saskatchewan and Ontario, and Baffin Island. There were also regions that were at least 20% wetter than normal, including: southern Northwest Territories; central Nunavut; small areas of Manitoba, Ontario, and Quebec; and the Atlantic provinces. Since the 1970s, precipitation across Canada has tended to be higher than the 1951–80 average. The wettest year on record, for the 62-year period of record, occurred in 2005 (13.4% above normal), and the driest was 1956 (7.3% below normal).

Comparing precipitation by decades, the 1980s was the wettest decade at 4.2% above normal. The remain-

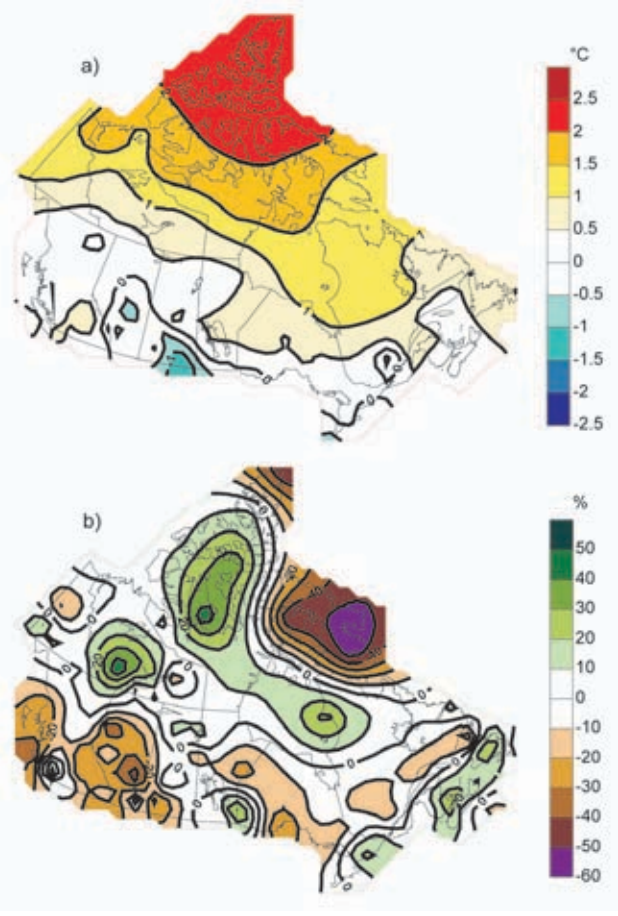


Fig. 7.2. (a) Annual mean temperature anomalies (°C) for Canada (based on 1951–80) for 2009 and (b) annual precipitation anomalies (% of 1951–80) for 2009. (Source: Environment Canada.)

ing decades in order from wettest to driest are: 1990s (+3.2%); 1970s (+2.5%); 2000s (+2.2%); 1960s (-0.8%); and 1950s (-3.0%).

Nationally, precipitation for each of the four seasons in 2009 was close to normal. Winter was right on normal with 0.0% (26th wettest); spring was the season with the greatest below-average amount of precipitation with -2.8% (22nd driest); the season with the greatest above-normal precipitation was summer with +2.2% (30th wettest); and autumn was -1.2% (21st autumn driest on record).

(iii) Notable events

It was a particularly intense fire season for British Columbia, which saw 3200 fires this year. Of those, 100 were considered significant with nearly half prompting evacuation orders. Wildfires scorched 68 000 hectares of land across the province—almost seven times more than the previous year's fire season. Costs of direct fire fighting were enormous, close to $400 million CAN or six times that budgeted, surpassing the most expensive season on record in 2003.

It was a long and deadly tornado season for Ontario, beginning on 25 April and ending on 28 September, claiming four lives. Ontario witnessed 29 tornadoes in 2009, which tied the record for the most tornadoes in one year, set in 2006. On average, the province sees 11 tornadoes each year. Three lives were lost during the 9 July F2 tornado in northwestern Ontario, an area where tornadoes are relatively rare. The fourth life was lost during the 20 August supercell storm when a boy was killed at a day camp. By the end of the day this storm system had produced at least 18 tornadoes—a record number of tornadoes in one day for Canada—and caused an estimated $100 million CAN in damage from Windsor through North Bay.

Manitoba's Red River recorded its second highest spring flooding in nearly 100 years. North of Winnipeg at Breezy Point and St. Clements, ice jamming caused the worst flood of the century, forcing full-scale evacuations. The ice jamming and flooding were caused by a number of factors, including: a wet autumn, heavy snow accumulation during the winter, a cool spring slowing snow melt, and a sharp change in temperature in mid-April that weakened the river ice which broke into large chunks later to jam down river. At the height of the flood, nearly 3000 people left their homes—more than half from First Nations communities. Near Morris, the metres-wide Red River grew to 16 km across, submerging rich farmland and highways. Total flood claims exceeded $40 million CAN with 500 homes damaged or destroyed.

Agriculture producers in Alberta and Saskatchewan faced one of the most challenging growing seasons in years with drought, cold, floods, and hail. Parts of the Prairies experienced their driest spring in 50 years and their coldest in 35 years. Cool weather delayed crop development by three to four weeks, and with the risk of frost continuing into July, producers never caught up even when killing cold and the first snows came much later than usual in mid-October. A dozen counties and municipal districts in Alberta declared a state of drought emergency or disaster.

Arctic ice continued to be a concern in 2009. In Canadian waters, sea ice extent was similar to that of 2008, but its spatial distribution was different. According to the Canadian Ice Service, greater-than-normal concentrations of ice occurred in the southeastern Beaufort Sea under prevailing northerly winds that carried some of the multiyear pack ice southwards. In the central and western parts of the Northwest Passage, thicker and more extensive ice led to delays in navigability of the southern route,

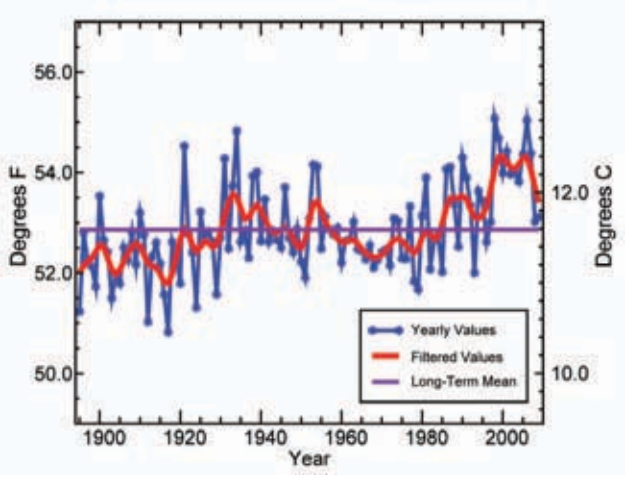


Fig. 7.3. Annual mean temperature for the contiguous United States, 1895–2009. (Source: NOAA/NCDC.)

while the northern route did not become truly navigable at all. By contrast, both routes were navigable in the summers of 2007 and 2008. Close to 80% of the Arctic sea ice was new, weaker, salty, and less than a year old. Further, old, durable multiyear ice was slowly thinning, more broken-up, and moving faster, which all contributed to melting earlier in the season. More information on Arctic sea ice can be found in Chapter 5.

Just before midnight on 2 August, a powerful storm moved out of the Rocky foothills and tracked southeastward across the province with wind and hail that left a devastating path of destruction to city and country. The main hail zone hit the extreme northeastern portion of Calgary. Inside the city, hail diameters reached baseball size and wind speeds peaked at 107 km hr^{-1}. In its wake, the storm left downed trees, broken windows and a swath of damage, knocking out power to several thousand customers. In some places, hail measured 10 cm deep. Canadian insurers estimated industry loss estimates at $500 million CAN, which made it the second or third largest catastrophic event in Canadian history. The massive hailstorm decimated over 600 000 ha of Alberta cropland spurring 1500 hail crop damage claims. In total, two-thirds of the year's hail crop losses occurred as a result of the long weekend storm.

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

Based on preliminary data, 2009 was the second consecutive year the nationally averaged temperature was 11.7°C, which is 0.1°C above the long-term (1895–2009) average. The year was characterized by extreme fluctuations in the weather pattern. The average temperature for the contiguous United States the first half of the year (January–June) was in the top tercile (25th warmest), while the average temperature during the last half of the year (July–December) was in the bottom tercile (37th coolest).

Below-average temperature anomalies in the central United States were associated with above-average precipitation anomalies. Overall, 2009 was the 18th wettest on record for the contiguous United States. Regionally, much-above-normal precipitation fell in the lower and middle Mississippi Valley, parts of the Southeast, and the middle third of the Atlantic Coast. The western third of the United States averaged below-normal precipitation for the year.

(i) Temperature

For the contiguous United States, the 2009 temperature very nearly tied 2008, which was the coolest since 2000 (Fig. 7.3). The spatial pattern consisted of cool anomalies in the northern and central U.S. Plains and Midwest, with warm anomalies in the Southwest and Florida (Fig. 7.4a). A persistent cool anomaly was entrenched in the U.S. Plains and Upper Midwest during the summer and fall periods. The decade long (2000–09) average annual temperature was 0.7°C above the twentieth century average. Over the past 30 years, the average temperature has increased at a rate of 0.4°C per decade.

As with most winter seasons, December 2008–February 2009 featured regional variations in temperature but the overall average for the contiguous United States was "near-normal," or within the middle third of historic winter temperatures. The warm anomalies strengthened in the spring (March–May), making it the 29th-warmest spring of the 115-year record. The warmer-than-average temperatures that were seen in the South and Southwest regions during the winter shifted to the West and Southwest regions during the spring.

The contiguous United States experienced its 44th coolest summer (June–August). A recurring upper-level trough in the Central United States was associated with cool Canadian air, bringing below-normal temperatures to the central and northern Plains, Midwest, and Great Lakes areas. The cool anomalies peaked in July, when six states (Ohio, Indiana, Illinois, Iowa, Pennsylvania, and West Virginia) experienced record cool temperatures for the month. It is noteworthy that an El Niño emerged during early summer 2009. Preliminary attribution exercises performed by NOAA scientists indicated that cooler-than-normal temperatures in the central United States during summer and early autumn are

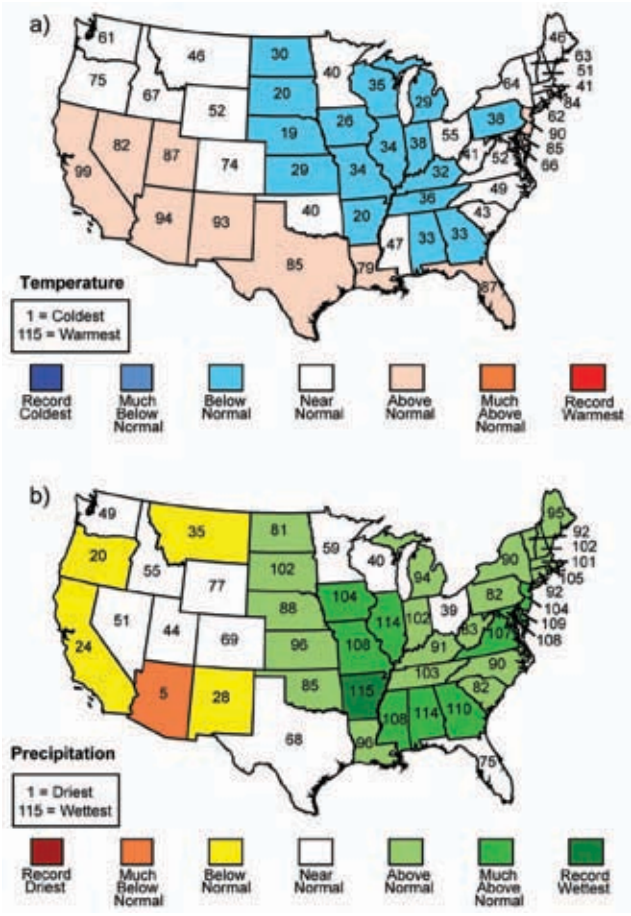


Fig. 7.4. Statewide ranks of (a) 2009 temperatures and (b) 2009 precipitation. A rank of 115 represents the warmest/wettest year since 1895. Much above-normal temperature/precipitation is defined as occurring in the top 10% of recorded years, which corresponds to a rank of 105–115. Above-normal temperature/precipitation is defined as occurring in the warmest/wettest third of recorded years (ranks 78–103). Much below-normal temperature/precipitation is likewise the bottom 10% of coolest/driest years since 1895, and below normal is defined as the remaining coolest/driest third of the distribution. (Source: NOAA/NCDC.)

not inconsistent with expectations during a developing El Niño episode (see sidebar).

Fall 2009 was a season of extremes for the contiguous United States. While September was about 0.8°C above the long-term average, October was marked by an active weather pattern that reinforced unseasonably cool air behind a series of cold fronts, creating an average temperature that was 2.0°C below the long-term average and ranked the nation as the fourth coolest October on record. During this month, 43 of the lower 48 states averaged temperatures that were below normal. Florida was the only state with an above-normal temperature for October. The following month was something of a mirror image, becoming the third warmest November on record, 2.2°C above the long-term average. Overall, the nationally-averaged temperature for the three-month autumn period was above-normal, ranking as the 34th warmest on record.

The average annual temperature for Alaska in 2009 was 0.5°C below the 1971–2000 long-term average. This represents the second consecutive annual period in which Alaska has experienced cooler-than-normal temperatures. Seasonal anomalies contrasted the contiguous United States, with both winter and spring temperatures below average. The summer and fall seasons were warmer-than-normal as 500 mb height anomalies increased.

(ii) Precipitation and snowpack

Average precipitation for the contiguous United States in 2009 was 64 mm above the long-term average of 740 mm. Precipitation across the United States in 2009 was characterized by persistent wetness in the Midwest and Southeast, while precipitation in the West, Northwest, and Southwest was below average (Fig. 7.4b). Arkansas observed its wettest year on record with four months of top three precipitation ranks (May, wettest; July, third wettest; September, second wettest; October, wettest). The unrelenting weather pattern also contributed to the second wettest annual period in Alabama and Illinois. More than half of the contiguous United States received above-normal precipitation for the year. Conversely, the lack of monsoonal moisture in the Southwest contributed to Arizona's fifth driest annual period. The decadal trend of the contiguous United States continued its above-normal precipitation streak with the past decade (2000–09) averaging 18 mm above the 20th century average and precipitation over the past four decades averaging 27 mm above the 20th century average.

It was the 22nd driest winter (December 2008–February 2009) for the contiguous United States in the 1895–2009 record. Texas recorded its driest winter period, while North Dakota experienced its wettest winter on record. The contrasts in rankings were the result of an active upper-level pattern that shuttled systems rapidly across the northern-tier states, while bypassing the deeper south. Conversely, the contiguous United States experienced its 18th wettest spring (March–May). Relatively slow-moving storm systems and surface fronts across the southern United States led to above-normal precipitation averages across the southeastern United States. Georgia experienced

its second wettest such period. Several other states experienced a spring period that saw above-average precipitation: Florida and Illinois (fifth wettest each), Alabama (seventh), and Arkansas (ninth). In March, record flooding occurred in parts of Minnesota and North Dakota along the Red River. The flooding was preconditioned by copious winter precipitation coupled with persistent precipitation-producing storms in the spring. Record-high flows were recorded along the Red River with peak levels exceeding the 500-year return interval.

Summer (June–August) precipitation was variable in 2009, which is typical for the season, but overall near normal, ranking 54th wettest out of 115 years. Regionally, the Northeast had its second-wettest summer on record, continuing a string of abnormally wet summer periods. Deficient monsoonal rains in the Southwest contributed to Arizona's third-driest summer. Precipitation averages in Georgia and South Carolina were also much below normal. Conversely, Massachusetts experienced its wettest summer and it was Maine's third-wettest such period.

It was the 11th wettest autumn (September–November) on record for the contiguous United States. Anomalously wet conditions in October led to a record wet month for the nation as a whole. The nationwide precipitation of 105.4 mm was nearly double the long-term average of 53.6 mm. Persistent precipitation during September and October made Arkansas' autumn precipitation its greatest ever. Nine other states were much above normal in terms of precipitation for the autumn season. Interestingly, these high precipitation anomalies occurred despite only two tropical cyclones (Tropical Storms Claudette in August and Ida in November) making landfall during the Atlantic Hurricane season. The variable climatic extremes continued in November when the upper-level jet retreated to the north, contributing to a nationally-averaged precipitation that ranked 18th driest, continuing the run of below-normal November precipitation in the contiguous United States. The summer and fall months were drier than average in much of Alaska.

During winter 2008/09, snowpack levels were below- to near-normal for the Cascade Mountains and the Northern Rockies in Idaho, Montana, western Wyoming, and Utah. The Olympic Mountains and Okanagan Highlands of Washington had snow levels less than 50% of normal. The Sierra Nevadas also experienced below-normal snowpack for the season. Conversely, the central and southern Rockies in Colorado, New Mexico, and northern Arizona had above-normal snowpack totals by the end of the season. Alaska snowpack was generally above normal, with the exception of the northern and southern coastal regions of the state.

March brought several large snowstorms that broke daily and monthly snow records across the center of the country. Statewide records for 24-hr snowfall accumulations were observed in Texas (64 cm), Oklahoma (66 cm), and Kansas (76 cm). Seasonal snowfall records were measured in International Falls, Minnesota, with 318 cm and Spokane, Washington, with 248 cm of snowfall.

The beginning of the 2009/10 snow season brought below-normal snowpack to the western United States, including much of Alaska, while Arizona and New Mexico observed above-normal snowpack. The low snowfall amounts contributed to ongoing drought in California. October and December were particularly snowy across the contiguous United States, with both months setting new snowfall extent records. October was North Platte, Nebraska's snowiest month on record with 77 cm, while December brought record snowfall to the Northeast corridor and the Plains, including Philadelphia, Pennsylvania; Washington, D.C.; and Oklahoma City, Oklahoma.

(iii) Droughts and wildfires

Widespread precipitation extremes occurred during 2009, with large areas (20–25%) of the country very dry (monthly precipitation total in the bottom tenth percentile of the historical record) during January, February, and November and large areas very wet (top tenth percentile) during May, June, October, and December. The dryness exacerbated areas of drought during early 2009 while the abundant precipitation brought drought recovery during the later months. The year began with 19.2% of the contiguous United States experiencing moderate to exceptional drought, as defined by the U.S. Drought Monitor (USDM). That percentage increased to 26.6% by late March before decreasing during the summer and fall, ending the year at 12.4%, which was among the lowest values in the ten-year USDM record. Based on the 110-year Palmer Drought Severity Index (PDSI) record, 2009 capped a decade of expansive drought, with the 2000–09 decade ranking as the third biggest drought decade in the last 110 years.

The drought epicenters during 2009 were southern Texas, the southern Appalachians, California, and Hawaii. Severe agricultural impacts were felt, especially in Texas and Hawaii. Low streams, reservoirs and stock ponds, and depleted soil moisture combined

to ravage agricultural (pasture, range, and crop) lands in Texas early in the growing season. Heavy irrigation of crops was required across much of Hawaii amidst low soil moisture and irrigation restrictions in some areas.

Beneficial rains beginning in September brought drought relief to southern Texas, but not before these areas turned in their driest September–August 12-month period in the 1895–2009 record. The PDSI plummeted to the extreme drought category by early summer, but it did not pass the levels of the record 1950s drought for southern Texas, both in terms of intensity or duration. An analysis of post oak tree-ring chronologies from 1652–1995 indicates that southern Texas has experienced a dozen individual years prior to the 20th century which had very low January–June precipitation similar to the lowest values of the past 110 years. The 1950s drought likely was matched and possibly exceeded by one that occurred during 1711–17.

Parts of the Southeast began 2009 with lingering moderate to extreme drought, but by the beginning of summer, drought in the Southeast was mostly gone. Parts of the Upper Mississippi Valley and adjacent western Great Lakes have been in some level of dryness or drought for most of the last seven years, with moderate to severe drought lingering at year's end. Northwest Wisconsin had the driest 12-month October–September period on record in 2009 (October 2008–September 2009).

Parts of the West, especially California, have suffered through three years of drought. Northern

STRONG SEASONALITY IN 2009 U.S. TEMPERATURES—NOAA CSI TEAM—M.P. HOERLING

What Happened?

Headlines regarding U.S. surface temperatures for 2009 should read "Strong Monthly and Seasonal Variability". This climate variability story is all too easily obscured by the mundane outcome that annually-averaged temperatures were just slightly above their 20th century average (+0.2°C). As illustrated in Fig. 7.5 (left panels), the year began (JFM) with much-above-normal temperatures (i.e., in the top quintile of the 115-yr record) over the Central and Southern Great Plains and the Desert Southwest, flanked to the north and east by below-normal temperatures. A southward expansion of cold conditions occurred across much of the Great Plains in the spring (AMJ). By the summer (JAS), much-below-normal temperatures shifted eastward, and a swath from the eastern Plains thru the upper Ohio Valley succumbed to record-breaking low July averaged temperatures. Meanwhile, the western third of the United States remained very warm during the summer, and September was the warmest month on record for California and Nevada. But that latter warmth too came to an abrupt end, with the West and Rockies experiencing much below temperatures during the fall (OND) that also engulfed the western Plains (notwithstanding a brief interlude of high temperatures during November). By all measures, a wild rollercoaster ride for U.S. temperatures through 2009!

Why did it happen?

Can any reason be given for this strong seasonality? Such seasonal extremes most certainly were not the result of human-induced climate change. It is known that the U.S. temperature impact of greenhouse gas (GHG) and aerosol forcing, as estimated from the climate models of the IPCC Fourth Assessment, is comparatively uniform across the seasons. Thus, the observed rapid swings between much-below- and much-above-normal temperatures in 2009 were unlikely a symptom of anthropogenic forcing. Natural processes of climate variability were instead more likely the dominant cause.

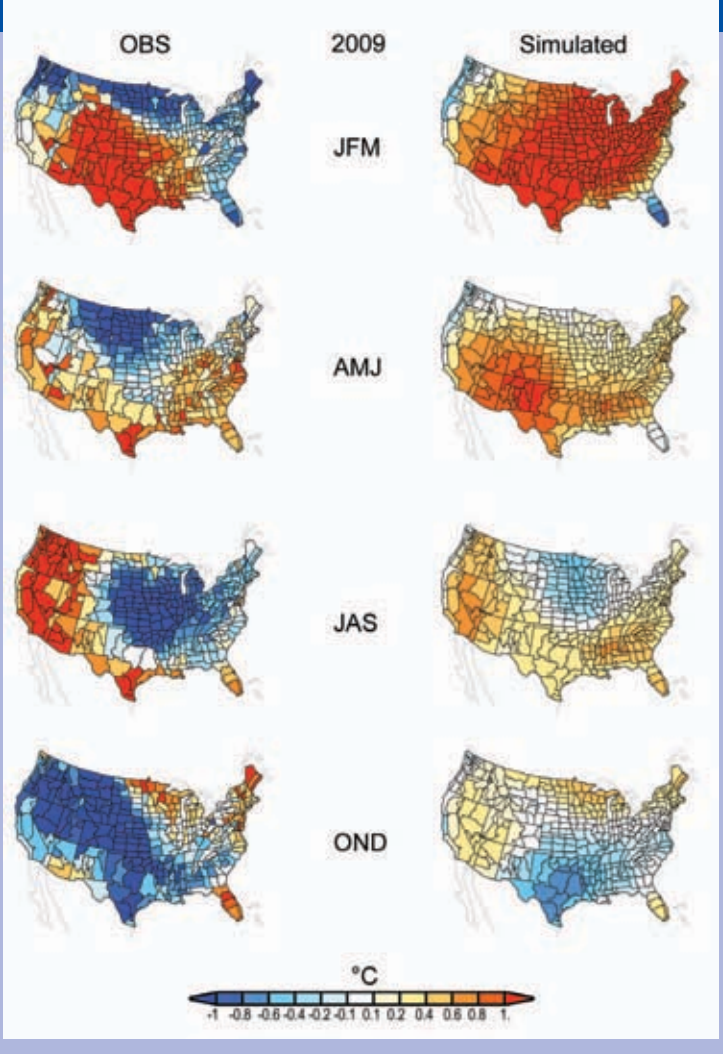
In the far-away reaches of the equatorial Pacific, a no-less dramatic seasonal reversal in SST conditions was taking place during 2009. La Niña conditions that developed in late 2008 persisted through March 2009. A swift transition occurred in early spring, leading to El Niño SST conditions by July. This El Niño increased to moderate intensity by October 2009. The impact of tropical east Pacific SST forcing on U.S. seasonal climate is well known, and the question we ask here is which, if any features of U.S. temperature seasonality may have resulted from the seasonal reversal in SST forcing. Six different global climate models were subjected to the monthly variability in observed 2009 global SSTs. The resulting ensemble-averaged seasonally varying U.S. temperature response (260 simulations in total) is shown in the right side plots of Fig. 7.5. Several qualitative aspects of the observed seasonality appear linked to fluctuations in the oceans. Notably, a warm JFM over much of the Great Plains gave way to cold conditions during JAS in the simulations. Likewise, the early winter warm conditions in the southern Plains and Gulf Coast were replaced by cold conditions in fall in the simulations. These simulated features are broadly consistent with the seasonality observed, and they

California began the year with moderate to extreme drought. Conditions improved throughout the year, but the state ended 2009 with areas of moderate to severe drought remaining. An analysis of blue oak tree-ring chronologies from the coast ranges of California revealed as many as seven three-year drought events in the 1332–1900 period which were more severe than the driest three-year drought events of the 20th to early 21st centuries.

The United States had a near-normal wildfire season for 2009, similar to 2008. The first half of the year was marked by above-average number of fires and acreage burned, primarily in the western and central regions of the country where ongoing drought had increased fire danger. The second half of the year was generally cool and wet for the nation and was associated with below-average fire activity. For the year as a whole, nearly 77 500 fires burned over 2 million hectares. Despite the near-normal season, the Station Fire in California burned an estimated 64 983 hectares, marking the largest recorded fire in Los Angeles County history and California's tenth largest fire since 1933.

(iv) Tornadoes

Across the United States, 2009 was a below-average year for tornadoes. As of February 2010, confirmed tornado reports and estimates for the end of 2009 indicated that there were 1150 tornadoes from January–December, which is below the 10-year (1999–2008) average of 1291 and the fifth lowest (sixth highest) total of the decade. The number of strong-to-violent



are mostly consistent with the known U.S. impacts of La Niña (during winter) and El Niño (during summer and fall).

By no means are all the seasonal features of 2009 U.S. temperatures interpretable as resulting from ocean forcing. In particular, the spatial scale and intensity of the observed cold summer conditions is considerably greater than the simulated SST-induced coolness. Likewise, the very cold conditions over the western United States during fall were apparently unrelated to that region's sensitivity to the SST forcings. These conditions are assumed to have resulted from purely atmospheric-driven variability. An important research task remains to ascertain how likely the cold summer and fall conditions were given both the state of global SSTs and anthropogenic GHG forcing in 2009.

Fig. 7.5. Seasonally averaged surface temperature departures (relative to 1971–2000) during 2009 based on NCDC climate division data (left panels), and climate simulations forced with observed monthly varying global sea surface temperature and sea ice conditions during 2009 (right panels). The simulations consist of 6 different models and a total ensemble size of 260 members conducted for 2009. (Source: NOAA/ESRL.)

tornadoes (rated EF3–EF5) reported in 2009 was 21, which is also below average.

There were 21 tornado fatalities in 2009, associated with nine tornadoes, which is the second lowest in the 1950–2009 record. The most deadly tornado of the year occurred in Oklahoma on 10 February, when an EF4 killed eight people. This was the state's first February EF4, and the deadliest February tornado in Oklahoma history. February was also the most deadly month of the year with a total of nine fatalities.

Louisiana and Alabama had their busiest tornado year of the decade, while the typically active states of Texas and Kansas had their second slowest. The largest outbreak of the year occurred on 9–10 April when 117 tornadoes were reported from Texas to North Carolina. A total of five tornado-related deaths were reported—three in Arkansas and two in Tennessee. There were also 221 straight-line damaging wind reports and 435 severe hail reports associated with the outbreak. According to preliminary data, November tied as the second quietest November since 1950 with only two tornado reports. In the past, November has been a fairly active month for tornadoes in the southeastern United States.

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

México experienced warmer-than-normal temperatures in 2009 and on average it was 10% drier than normal. México's National Meteorological Service (SMN) reported a national precipitation average of 681.9 mm, compared with a historical average of 759.6 mm (1971–2000). The nationwide annual mean temperature was 22.5°C, which was 1.0°C above the long-term climate average. Extreme weather caused several deaths and millions of dollars in damages to the agricultural and water sectors.

(i) Temperature

In general, México registered an annual temperature anomaly in a range from -1.0°C to +1.0°C, which is considered a normal variation. With the exception of the Baja California Peninsula, northwestern, northern, northeastern, and western regions, as well as the Yucatan Peninsula, the anomalies were between 1.0°C and 2.0°C above normal (Fig. 7.6a). Annual mean temperature for the country as a whole was 22.5°C, with an anomaly of 1.0°C above normal. However, spatial and temporal variations were observed. During the winter, spring, and summer, anomalies from +1.0°C to +4.0°C were found in the northern, northwestern, western, and central regions of the country as well as in the Yucatan Peninsula. Recovering from the rainy season, at the end of August and beginning of September temperatures quickly decreased to normal in most of these regions, with the exception of the Yucatan Peninsula and the southeastern regions, where anomalies between 1.0°C and 2.0°C above normal remained.

By the end of November and during December, unusually low temperatures prevailed in the northwestern, northern, western, and central regions of México; in the states of the northern Gulf coast; and in the Sierra Madre Oriental and the Eje Neovolcanico regions. The anomalies were as much as 4.0°C below normal. This behavior was related to intense humidity from the tropical Pacific and its interaction with cold fronts; these conditions resulted in cloudier-than-normal skies, which led to low diurnal temperatures in most of the country.

(ii) Precipitation

The rain pattern was variable during the year and across the country, but was generally very dry (Fig. 7.6b). The year began much drier than normal in the winter and spring, but it changed to normal precipitation in the beginning of the rainy season (May–June).

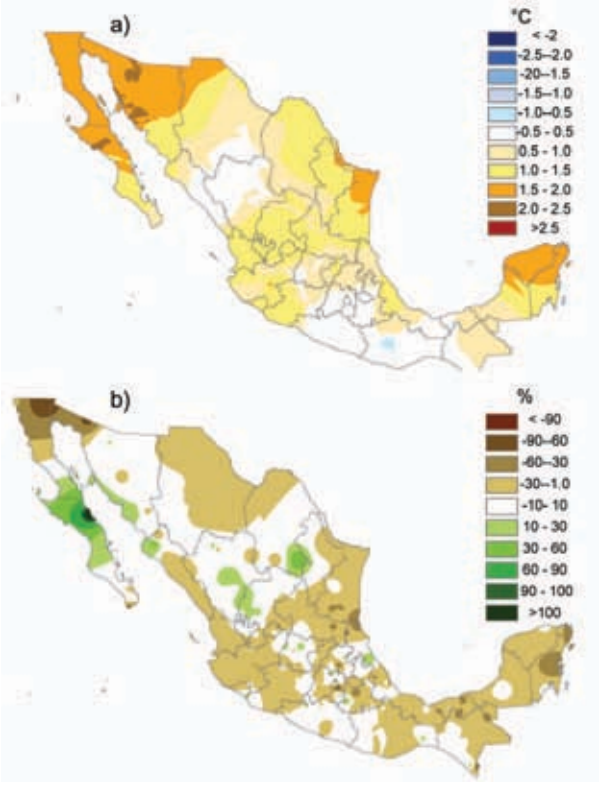


Fig. 7.6. (a) Annual mean temperature anomalies (°C) for Mexico (based on 1971–2000) for 2009 and (b) annual total precipitation anomalies (% of 1971–2000) for 2009. (Source: National Meteorological Service of México.)

The first drought occurred in March and April and produced some impacts in the southern and southeastern states of the country. Thousands of livestock and hundreds of thousands of dollars U.S. were lost by the end of April, seriously impacting the economy of Tabasco. The development of the rainy season during May and June allowed the scheduled farming activities in most of the country; however, a new drought developed as a consequence of the fast appearance of El Niño. This drought episode hit agricultural, cattle, and water sectors in most of México.

Precipitation statistics ranked July 2009 as the driest since 1941 at a national level. Due to the devastating impacts, some farmer organizations in the central region of the country declared the event as the worst drought in 70 years.

Precipitation recovered in the western, central, and southern areas of México in the beginning of September, with an exceptionally wet autumn. However, the total annual precipitation reported by the National Meteorological Service was below normal (Fig. 7.6b). The largest negative annual anomalies were registered in Distrito Federal (-47.7%), Nayarit (-24.7%), Tabasco (-23.6%), Yucatan (-22.7%), Quintana Roo (-22.4%), Aguascalientes (-22.2%), Sinaloa (-20.0%), Estado de México (-19.8%), Jalisco (-18.4%), Michoacán (-18.3%), Veracruz (-16.8%), Morelos (-14.9%), Chiapas (-14.5%), Queretaro (-12.4%), and Chihuahua (-11.8%). Only five of the 32 states of Mexico reported rainfall above normal: Baja California Sur (+69.6%), Baja California (+26.6%), Hidalgo (+11.3%), Zacatecas (+6.7%), and Sonora (+4.5%).

(iii) Wildfires

According the National Forest Commission (CONAFOR) reports less than 10 000 wildfires were observed during 2009 in the country. Most were registered during the period from February through July. The states with the highest occurrence of fires were México, Distrito Federal, Michoacán, Chihuahua, Puebla, Jalisco, Chiapas, Tlaxcala, Hidalgo, and Baja California. Those with the highest affected areas were Baja California, Quintana Roo, Coahuila, Yucatán, Oaxaca, Zacatecas, Chiapas, Michoacán, Guerrero, and Chihuahua.

c. Central America and the Caribbean

1) Central America—J. A. Amador, E. J. Alfaro, H. G. Hidalgo, E. R. Rivera, and B. Calderon

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

(i) Temperature

Most stations located on the Pacific coast show, for 2009, very little surface temperature departures from

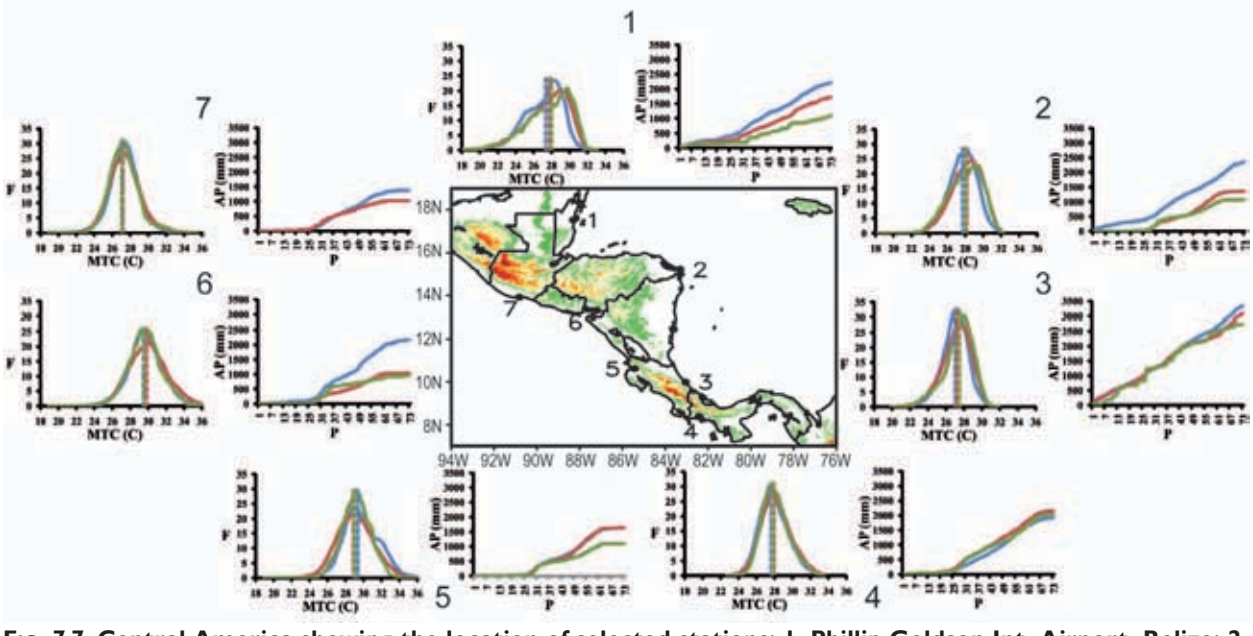


Fig. 7.7. Central America showing the location of selected stations: 1. Phillip Goldson Int. Airport, Belize; 2. Puerto Lempira, Honduras; 3. Puerto Limon, Costa Rica; 4. David, Panama; 5. Liberia, Costa Rica; 6. Choluteca, Honduras; and 7. San Jose, Guatemala. For each station, surface temperature frequency is shown on the left and accumulated pentad precipitation on the right. Blue represents climatology for the base period 1971–2000, red the 2000–09 decade and green 2009. Note that San Jose does not show 2009 precipitation data due to large amount of missing data. (Source: NOAA/NCDC.)

their climatology or from their 2000–09 averages (Fig. 7.7). Stations located on the Caribbean side present a shift toward the right in their frequency distribution, implying a warmer year than normal. Distribution for the 2000–2009 decade confirms, in general, a warmer decade than normal.

(ii) Precipitation

The year was generally drier-than-normal for three of the seven stations analyzed: Phillip Goldson A. (Belize), Puerto Lempira (Honduras), and Liberia (Costa Rica). None of these sites show dry conditions exceeding the 95% confidence level with respect to the mean. In terms of the starting and ending dates (SD and ED) of the rainy season, there is a general tendency for 2009 being a year with late SDs when compared to both the baseline period and 2000–09 average. Also, the 2009 rainy season had an early ED for Liberia, compared to the averages for 1971–2000 and 2000–09, while Choluteca shows an early ED compared to 1971–2000 but a late ED compared to 2000–09. David behaves in an opposite way to Choluteca. These variabilities suggest more local than regional physical mechanisms controlling precipitation.

The number of five-day rainy events (pentads) during 2009 was lower than average in six of the seven stations analyzed. The exception was Puerto Limon (Costa Rica). Conversely, the 2009 number of dry pentads was higher than normal for four of the seven stations analyzed (Phillip Goldson, Puerto Lempira, Liberia, and San Jose), while Choluteca and David were lower than normal and Puerto Limon was about average. The interquartile range (IQR, a measure of variability for the pentad data) was about average in all stations, except for San Jose. Finally, the number of wet outliers was lower than normal for San Jose, Lempira, Choluteca, David, and Liberia; slightly less than average for Belize; and above average in Limon. Most below-normal precipitation in the Pacific slope of Central America can be associated with a warm ENSO condition for the second half of the year and stronger-than-normal winds associated with the Intra-Americas Seas (IAS) low-level jet. A cold or near-neutral ENSO condition during northern winter 2009 did not reflect in relevant departures from normal conditions in the region.

(iii) Tropical cyclone activity

Tropical cyclone activity in the Caribbean was below normal during 2009. There were two named storms in this region (nine in the Atlantic) and one hurricane (three in the Atlantic). No strong hurricanes (category > 2) were observed in this region (two in the Atlantic). Typical values (given by the median) in the Caribbean during the last four decades are four named storms, two hurricanes and one strong hurricane. As a consequence of this decrease in tropical cyclone formation, Central America experienced reduced societal impacts caused by hurricanes. Of special interest for the region was Hurricane Ida. This storm originated over the Caribbean Sea on 4 November, and moved ashore over Nicaragua the following day. After reemerging over the Caribbean, the storm gradually grew stronger as it moved northward.

(iv) Notable events

According to the Costa Rican National Meteorological Institute, 16 easterly cold waves were observed between June and October. There were 12 cold outbreaks in the Caribbean Sea during 2009, in contrast to the observed typical value of 16 events per year (relative to 1975–2001). In El Salvador, deadly floods and landslides, associated in part with Hurricane Ida, claimed 192 lives. The National Electricity Board of Costa Rica (ICE in Spanish) reported an additional investment of more than $5 million U.S. to produce thermal electricity. This additional production of thermal energy was necessary due to the drier-than-normal year.

2) The Caribbean—C. Fonseca Rivera, B. Lapinel Pedroso, R. Pérez Suárez, A. Carrión Romero, A. León Lee, V. Cutié Cancino, I. González García, 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, 2009 was characterized by mean temperatures above the long-term average (1971–2000), resulting once again in a warm year. The annual mean of 25.9°C ranks 2009 as the 10th warmest year since 1951 (Fig. 7.8a). This behavior was strongly influenced by an increase in extreme temperatures and high values reported in the summer. It highlights July, August, and September as the warmest since 1970. Also October 2009, where the values were 1°C above normal, was the warmest October since 1970.

For Jamaica, slightly-above-normal temperatures were recorded for some coastal stations. This was observed against negative sea surface temperature anomalies around Jamaica for the first half of the year with a shift to positive anomalies for the latter half of the year.

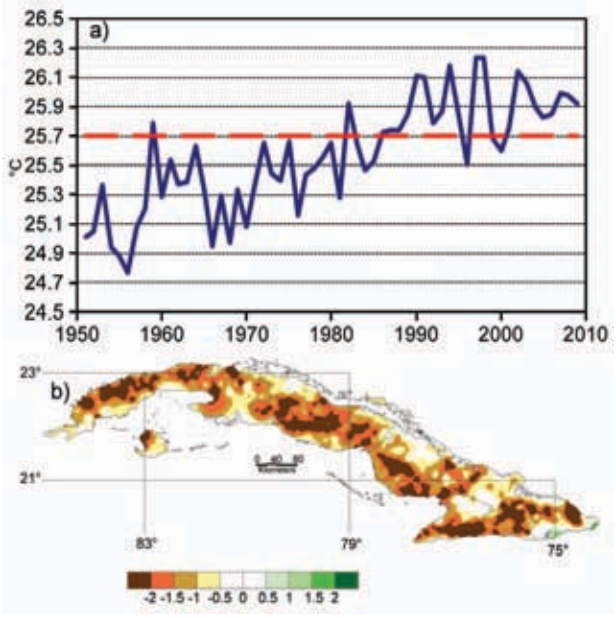


Fig. 7.8. (a) Annual mean temperature for Cuba, 1951–2009 and (b) annual precipitation anomalies, represented as Standardized Precipitation Index (based on 1971–2000) for 2009. (Source: Institute of Meteorology of Cuba.)

Temperatures across Puerto Rico ranged from 7.2°C in Adjuntas, which was recorded on both 28 February and 23 March, to 36.1°C in Ponce, which occurred on 30 July and 10 August. By the end of the year, 2009 ranked as the 4th warmest year since record began at the Luis Muñoz Marin International Airport in 1956 (the daily mean temperature was 27.4°C versus the 30-year normal of 26.6°C). Temperatures across the U.S. Virgin Islands ranged from 15°C at Beth Upper New Works near Christiansted on Saint Croix (recorded on 14 and 28 January), to 34.4°C, also at Beth Upper New Works (on 20 July). The annual mean temperatures at the Cyril E. King Airport on Saint Thomas, and at the Christiansted Airport on Saint Croix, were both 27.2°C in 2009; these values ranked near their long-term average of 27.2°C and 27.6°C, respectively.

(ii) Precipitation

For Cuba, the annual total rainfall for 2009 was below average (Fig. 7.8b). The deficit amounts of rain which affected the three regions of Cuba were 24% below the mean, resulting in the 2nd driest year since 1961. At the end of dry season (November 2008–April 2009) which usually represents 25% of the annual total, only an accumulated value of 18% was observed. The western region ranked as one of the 10 lowest since 1961. Also, the rainy season (May–October 2009) finished with marked deficits in the country, accumulating only 60% of the annual total, and ranked 4th driest for the same period.

For Jamaica, the average annual rainfall for 2009 was below normal. This manifested as below-average rainfall for nine months, particularly during the latter half of the year (Fig. 7.9). Barring these, near-normal rainfall amounts were recorded in January while above-normal values were measured during February and May. February, a usually dry month, received 128 mm of rainfall which represented the 13th wettest February on record. The primary cause during that month was the frontal systems and troughs, and the northeastern parishes received much of this rainfall. Also noteworthy were the rainfall amounts recorded for July (57 mm) and October (168 mm), which respectively represented the second and seventh driest monthly totals on record. All 14 parishes experienced below-normal rainfall in July. For October, only two parishes recorded above-normal rainfall. The rainfall deficit experienced during the Caribbean rainfall season (June–November) was related to the appearance and subsequent persistence of El Niño conditions since June 2009. The El Niño contributed to increased vertical wind shear in the main development region over the tropical Atlantic and appeared to have offset the effect of the ongoing multidecadal signal. There were no hurricanes impacting Jamaica.

In Puerto Rico, just before the hurricane season began, the presence of several persistent upper-level lows across the southwestern Atlantic, contributed to wetter-than-normal precipitation during April through June (this wet start to the year can been seen in the blue shading in Fig. 7.10). By the end of the year, cooperative weather stations indicated that Puerto Rico experienced another near-normal year, receiving 97% of its normal rainfall; however, precipitation varied from 55% to 113% across the U.S. Virgin Islands in 2009.

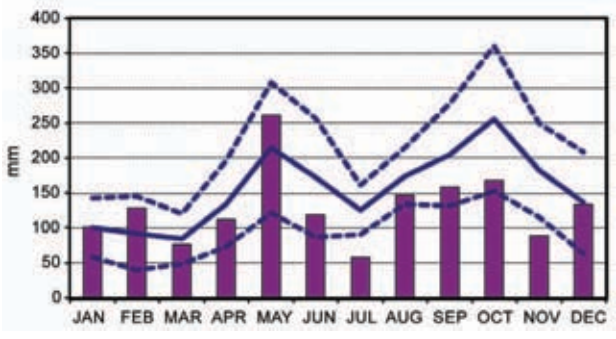


Fig. 7.9. Monthly Jamaican rainfall for 2009 (bars), climatology (black), and one standard deviation from climatology (dashed). The reference period is 1961–90. (Source: Meteorological Service of Jamaica.)

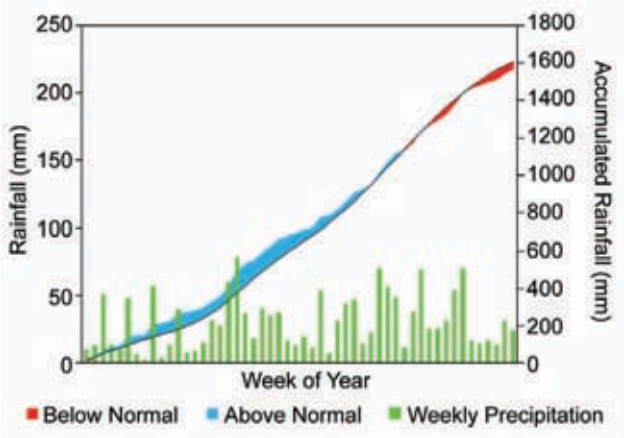


Fig. 7.10. Weekly mean rainfall for Puerto Rico, based on over 50 cooperative weather stations, with accumulative rainfall displayed on the right hand axis of chart. Year to date surpluses and deficits displayed with blue and red shading respectively. (Source: NOAA/NWS.)

(iii) Notable events

A significant drought started in Cuba during the dry season (November 2008–April 2009). This event affected large areas in the western and central regions. Later, the drought continued across the country and during the rainy season (May–October 2009), which was extremely dry. At the end of 2009, nearly 60% of the country showed moderate to severe dry conditions. This event is consistent with the increasing trend observed in the anticyclone influence on the area in recent decades accompanied by persistent and severe drought.

Meteorological drought conditions persisted in Jamaica from January to November 2009 for 3 of the 14 parishes, interrupted only by May rains. The parishes affected were Clarendon, St. Thomas, and St. Mary.

In Puerto Rico, on 15 November, record flooding was observed along the Rio Piedras in San Juan—the river crested at an all time high of 7.2 meters—resulting in major flooding across the interior portions of the San Juan metro area. This rainfall event contributed to the 308 mm of rain that accumulated at the Luis Muñoz Marin International Airport during November, making it the wettest month since April 2005. However, the year's heaviest 24-hr rainfall came on Christmas Eve, when the remnants of a cold front moved across Puerto Rico dropping 229 mm of precipitation across the municipality of Aibonito, located in the eastern interior of the island. This rainfall event led to significant flash flooding and mudslides, including the destruction of dozens of homes in the municipality of Aibonito, which prompted the governor of Puerto Rico to declare an emergency zone for the affected areas after the event.

d. South America

The 2009 annual mean temperature was generally near normal to above normal across South America (Fig. 7.11a). Significant positive anomalies were mainly observed in Venezuela, Peru, Brazil, Bolivia, Paraguay, and Argentina. Overall, the annual total precipitation was near normal to below normal except for some small regions in northern and southern Brazil. The main negative anomalies were found in Venezuela, Brazil, Chile, and Argentina (Fig. 7.11b).

1) Northern South America and the tropical Andes—R. Martinez, A. Mascarenhas, E. Jaimes, G. Leon, A. Quintero, and G. Carrasco

Countries considered in this section include: Venezuela, Colombia, Ecuador, Peru, and Bolivia.

(i) Temperature

The temperature and precipitation behaviors were mainly associated with the ENSO evolution during the second half of the year. The 2009 annual mean temperature anomaly was near +1°C in Venezuela. In Colombia, the temperature was near normal during the first half of the year while a gradual increase was observed during the second half of the year with anomalies between +1°C and +3°C almost everywhere across the country. The stronger anomalies were found in September and December when historical maximum temperature records were registered. In Ecuador, the mean temperature was above normal in the first quarter of the year except for the central and northern Ecuadorian Andes. In Peru, the annual mean temperature was mainly near normal with an anomaly near +1°C in the east; however, several frosts occurred in the southern and central Andes zones in August and September.

(ii) Precipitation

In Venezuela, dry conditions were predominant during 2009. During the dry season (February–March), the rainfall deficit was near -60 mm. This deficit increased during May–June (start of the rainy season) when it reached between -140 mm to -180 mm, especially over Portuguesa, Guárico, Apure, and Monagas states. The dry conditions affected rice and corn crops in these areas. From August to October, precipitation deficit fluctuated between -140 mm and -220 mm over the center and south zones extending to the Andean region and continuing to December. The main impact of this deficit was evident in the agriculture and energy sectors. Seventy percent of the national energy production comes from El Guri

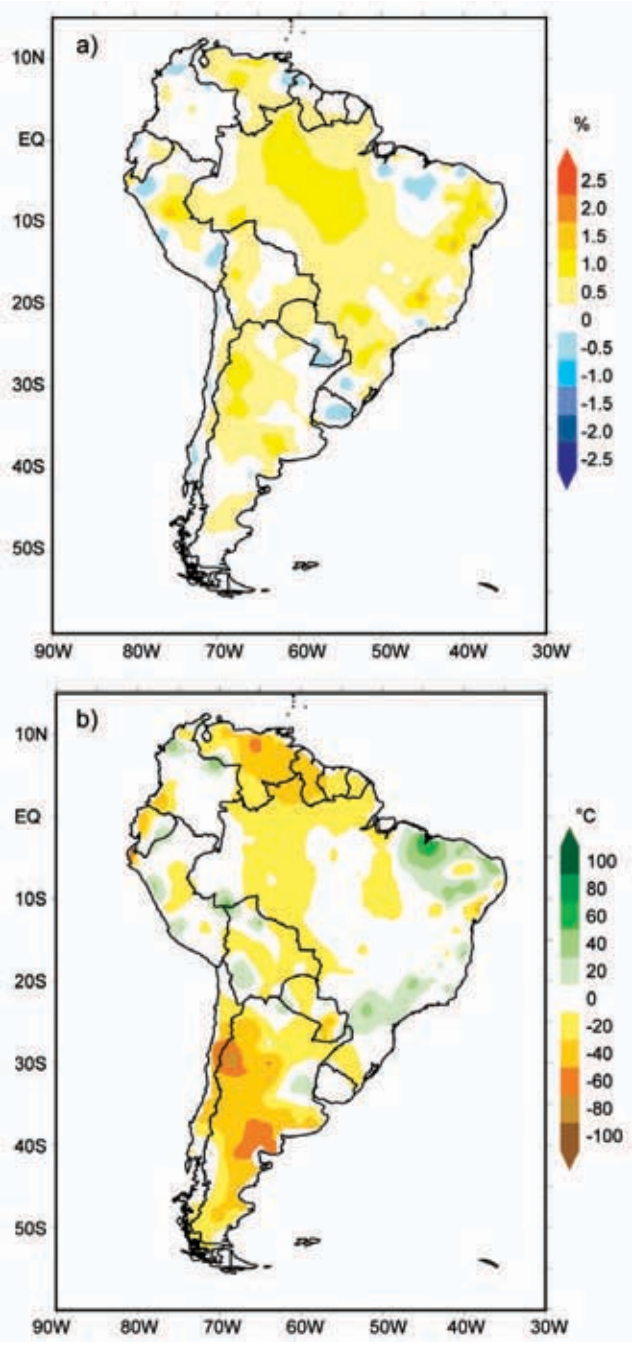


Fig. 7.11. (a) Annual mean temperature anomalies for South America (based on 1971–2000) for 2009 and (b) annual precipitation anomalies (% relative to 1971–2000) for 2009. Sources: National Meteorological Services of Argentina, Brazil, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay and Venezuela. Data compilation and processing by CIIFEN 2009.

Hydroelectric Plant (Caroní River Basin in Bolivar State). The reservoir was severely affected by the precipitation deficit with an 11 m below-average water level, leading to an electric power restriction at the national level.

In Colombia, positive precipitation anomalies between +40% and +70% were predominant across the country from January to March, especially in the Andean region. When the Tropical Pacific sea surface temperature switched from neutral to warm conditions, precipitation anomalies became negative. Negative anomalies between -40% and -70% were observed in the last quarter of 2009 over the Caribbean, Andean, and Pacific regions.

In Ecuador, negative anomalies were registered from January to May in the coastal and Andean zones. The deficit reached 60% of the normal value. During the second half of the year, the rainfall deficit was generalized over the entire country. Severe restrictions were imposed on the use of hydro energy during November and December.

In Peru, the precipitation anomalies were mostly negative during the first quarter of the year, especially in the southern zone where they reached -60% to -100%. In contrast, in April–June, precipitation anomalies became positive, registering up to 100% in the northern and central Amazonia and causing some floods. The possible cause of these rainfalls could be the typical moisture flux coming from the north. This humidity continued in July–August but with minor intensity. The southern region of Peru registered snow and hail storms which paralyzed transportation in this area. In September–October, negative precipitation anomalies down to -80% were registered in northern and central Amazonia, while negative anomalies down to -100% were observed in the southwest of the country. This caused a deficit in the water level of the Titicaca Lake (Puno).

In Bolivia, negative precipitation anomalies were also found in January–February in several regions: the Altiplano (-16%), the Valleys (-62%), the eastern Llanos-Santa Cruz (-64%), and the Bolivian Chaco (-71%). This condition persisted from April to October in the Valleys, Beni, and Chaco regions. In northern La Paz, negative anomalies of -49% were observed during the last quarter of 2009. In contrast, Pando in northern Bolivia observed positive precipitation anomalies all year; December was the rainiest month with +58%. Precipitation anomalies from +25% to +50% were also observed during February–March in the eastern Llanos-Santa Cruz while in the Altiplano, anomalies between +58% and +84% were registered in November–December.

(iii) Notable events

In Venezuela, one of the reported extreme events was the occurrence of a small tornado in San Cris-

tobal which damaged public services and basic infrastructure in the city. These events have become more frequent in Venezuela during the last years.

In 2009, several extreme events occurred in Peru. On 11 April and 14 April, precipitation exceeded the monthly means in Jauja, Huayao, and Tarma. On 12 July, 25 cm of snow was observed in Tumayhuarapa and Pampachiri (Andahuaylas, Southern Highlands of Apurímac). On the first days of November, nine hours of continuous rainfall with winds of 50 km hr^{-1} were reported in Nauta-Iquitos (Northern Amazonia).

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

Countries considered in this section include: Brazil, east Bolivia, Paraguay, and north Argentina.

La Niña-like conditions were present in early 2009, followed by the development of El Niño patterns starting in June 2009. During June–September, sea surface temperatures were generally about 1°C warmer than the long-term average across the central and eastern equatorial Pacific. Considering the summertime mean of the 2000–09 decade for the tropical region east of the Andes, this decade showed less rainfall (about 200 mm below normal) as compared to 1980–90 (about 350 mm above than normal), while air temperatures were 0.5°C to 2°C warmer. The annual mean temperature and total rainfall anomalies are presented in Figs. 7.11a and 7.11b, respectively.

(i) Temperature

Most of tropical South America east of the Andes experienced a warm 2009 austral summer, with maximum temperatures 3°C to 4°C warmer than normal in the South American monsoon area in southeastern Brazil and in the coastal region of northeast Brazil. Likewise, warm summer conditions (1°C to 2°C above normal) were observed in central and eastern Amazonia and eastern Paraguay. In April, mean temperatures were about 3°C–4°C above normal over western Paraguay and northern Argentina, with maximum temperatures reaching 5°C higher than normal in Paraguay. Average temperatures during May were about 2°C above normal in central Amazonia, northern Paraguay and eastern Bolivia.

In June, cooler-than-normal conditions (anomalies of -0.5°C to -1°C) were observed in southern and southeastern Brazil, and some sectors of western Amazonia, due to an episode of cold air intrusion. Maximum/minimum temperatures in southern Brazil were 2°C–3°C cooler than normal, and frost was reported in the elevated regions of southern Brazil. The cooling was also observed in Paraguay, where minimum and maximum temperatures were about 4°C and 1°C below normal, respectively.

In July, cold temperature anomalies were detected in eastern Amazonia, northeast Brazil, southern Paraguay, and northern Argentina. Minimum temperatures were 3°C colder than normal in southern Brazil and in some regions of southeastern Brazil and western Amazonia and 4°C colder than normal in southern Paraguay. This cooling was due to a cold front penetration during late July. In the city of São Joaquim, state of Santa Catarina in southern Brazil, temperature reached -6.2°C on 24 July. Cold temperature anomalies also persisted over southern Paraguay. On the other hand, warm temperature anomalies (1°C–3°C) were detected in central and southeastern Brazil and over the Amazon region.

In August, most of tropical South America east of the Andes was about 1°C–2°C warmer than normal. In September, the eastern coast of northeast Brazil was about 3°C warmer than normal, while the rest of the tropical region was 1°C–2°C warmer than normal.

October temperatures across most of tropical South America were 1°C above normal, with the largest warming over Amazonia and southeastern Brazil. In November, temperatures were warmer than normal in southern and southeastern Brazil and western Amazonia. The largest warming was detected over northern Paraguay where the mean temperatures were 4°C–5°C warmer than normal. In December, temperatures in most of tropical South America east of the Andes were 1°C–2°C warmer than normal, especially over northern and eastern Amazonia and southeastern Brazil. In some regions of southeastern Brazil, temperatures were 4°C warmer than normal during the second week of December.

(ii) Precipitation

Most of the austral summer and fall months were characterized by episodes of intense rainfall and floods in large cities such as Sao Paulo and Rio de Janeiro, as well as in most of tropical South America, north of 5°S. This was due to the presence of the South Atlantic Convergence Zone (SACZ). Northwestern Amazonia observed more than 200 mm above normal. This intense rainfall was the main cause of the record high levels of the Rio Negro River in Manaus in July (see sidebar), the highest level in 107 years of measurements. Northeast Brazil was also severely affected by heavy rainfall and flooding in April and May, otherwise the dry season was predominant in that region.

EXTREME RAINFALL AND THE FLOOD OF THE CENTURY IN AMAZONIA 2009—JOSE. A. MARENGO

During the austral summer and winter 2009, the Amazon basin, drained by the Amazon River and its tributaries, was hit by heavy flooding. This year the water level rose higher and stayed longer than it has in several decades. According to national and international press, almost 376 000 people were left homeless and 40 died because of the floods. The communities living on the river banks and on the urban areas of cities like Manaus suffered the impacts of the rising waters, and the floods affected the exotic wildlife and the endangered species. Damages were estimated on the order of $200 million U.S. in the Brazilian state of Amazonas.

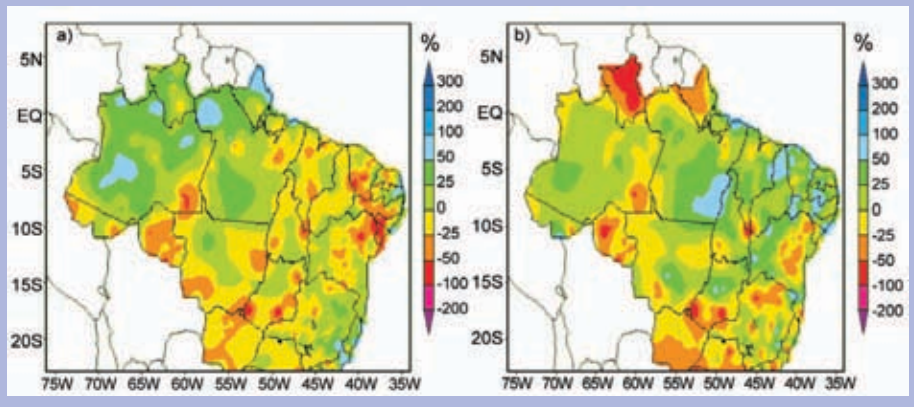


Fig. 7.12. (a) December 2008 to February 2009 rainfall anomalies and (b) February to May 2009 rainfall anomalies (% relative to 1961–90). (Source: CPTEC/INPE.)

During the summer (December 2008–February 2009), above normal rainfall was found in the entire Amazon region (Fig. 7.12a), reaching 100% above normal in northern and western Amazonia, where the basin of the Rio Negro is located. Brazil's Center for Weather Forecasts and Climate Studies reported large rainfall anomalies during January and February 2009. During late summer and fall (Fig. 7.12b), rainfall in northern and central Amazonia was between 25% and 50% above normal, and the largest rainfall anomalies (up to +100%) were detected in the border region of eastern Amazonia and northeast Brazil. In central Amazonia, rainfall in April, May, and June was between normal and above normal. In the city of Manaus, during the first 15 days of June 2009 it rained almost 30 mm above the climatology for that month (117 mm).

According to the measurements of the State University of Manaus (UEA), the heavy rainfall of January–February in northwest Amazonia led to high water levels of the Solimões River at Tabatinga in March–April. The water levels reached 12.5 m, compared to the long-term climatology of 11.8 m. The water levels of the Rio Negro at Manaus and the Amazonas at Obidos reached high values a few months after. The level of Rio Negro at Manaus reached maximum values between May and July. The measurements at Manaus site reflected the contribution of the Rio Negro and, to some degree, the Rio Solimões that extend over Amazonia. It takes about four to five months for rain falling on the upper basin of the Rio Negro in northwest Amazonia to travel downstream to the Manaus gauge site. Therefore, the anomalously high levels measured during June and July were due to the intense rainfall that fell during January and February over northwestern Amazonia and, to a lesser degree, to the intense rainfall in May and June over central Amazonia, where the rainfall takes one month or less to reach the gauge site at Manaus.

Historically, according to the Brazilian Geological Survey, the floods in Amazonia in 2009 show the highest levels in the history. In July, the level of the Rio Negro in Manaus reached 29.75 m, a new record high since the beginning of data collection in 1903. The five previous records observed in Manaus were: 29.69 m (1953; Fig. 7.13), 29.61m (1976), 29.42 m (1989), 29.35 m (1922), and 29.17 m (1908). Levels of the Amazon River at Óbidos and the Tapajos River at Santarem also showed records highs. Furthermore, the levels of the Amazonas, Marañón, Napo, and Corrientes Rivers in the Peruvian Amazon also experienced record level/discharge highs, according to the meteorological service of Peru (SENAMHI).

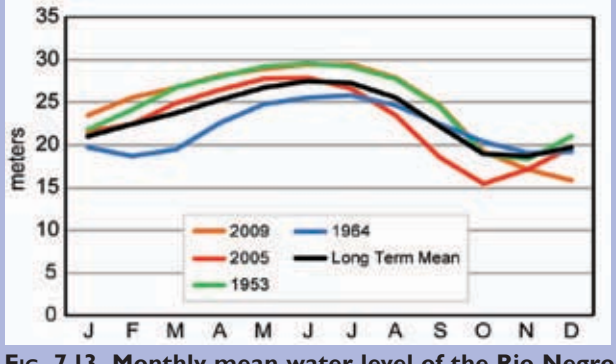


Fig. 7.13. Monthly mean water level of the Rio Negro in Manaus, Brazil, for some extreme years: dry (1964, 2005), wet (1953, 2009), compared to the 1903–86 average. (Source: CPTEC/INPE.)

During the austral fall, northeastern Brazil, Amazon region, and northern Bolivia observed normal rainfall. The largest anomalies were observed on the border between eastern Amazonia and northeast Brazil, with rainfall anomalies greater than 100 mm per month until June, which normally marks the beginning of the dry season. The ITCZ was intense. In some places in the Amazon, rainfall was 300 mm above normal. In the Peruvian Amazonia, the river levels were about 1 m–2 m above normal. In northeast Brazil, 49 deaths occurred as a consequence of floods. More than 408 000 were left homeless and damages to highways and irrigation structures were reported. In May, eight people died because of the breaking of a small dam in the state of Piauí in Northeast Brazil, and 600 families were forced to leave their houses. The estimated losses due to the floods in Brazil until July were about $800 million U.S. On the other hand, during April, a severe drought was reported in Paraguay, with negative precipitation anomalies around -160 mm in the south of the country. This represents a new historical record minimum precipitation for that month.

During the spring (September–November), when the rainy season normally starts, anomalously wet conditions were reported in most of southeastern South America, causing floods in Paraguay, where thousands of people were forced to evacuate along the Paraná River. The anomalously wet conditions detected over most of this region affected the harvest of rice and other vegetables.

In November, while extremely large rainfall anomalies were detected over Uruguay, southern Brazil, southern Paraguay, and northern Argentina, dry conditions were reported on the coast of Ecuador and the South American monsoon region. In the same region, the last two weeks of November were characterized by dry weather and relative humidity of about 15%. In December, very wet conditions (rainfalls of 100 mm–150 mm above normal) were reported in southeastern Brazil and northern Paraguay. Intense rainfall and landslides in the city of Angra dos Reis, Rio de Janeiro, killed 53 people on New Year's Eve, and intense rainfall episodes were detected in most of southeastern South America in December. From 31 December 2009 to 1 January 2010, the total rainfall was 275 mm in Angra dos Reis. The cities of Cochabamba, Chuquisaca, Tarija, and Santa Cruz in Bolivia were affected by floods, forcing more than 10 000 families into food insecurity. During the last three months of 2009, rainfall was below normal in Northeast Brazil.

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

Countries considered in the section are Chile, Argentina and Uruguay. The annual mean temperature and total rainfall anomalies for Southern South America are in Figs. 7.11a and 7.11b, respectively.

(i) Temperature

In Argentina and Uruguay, above-normal temperature was observed during austral autumn (MAM), with mean anomalies ranging from +0.5°C to +1.5°C. Anomalies from +2.0°C to +3.0°C in west-central Argentina during these months led to the warmest austral autumn over the past five decades. In contrast, the austral winter (JJA) brought cold conditions. For instance, the mean temperature in July was more than 3°C below normal in northeastern Argentina, southern Paraguay, northern Uruguay, and southern Brazil. July 2009 was the second coldest July of the past 50 years (after July 2007) for many locations in Uruguay and Argentina. In August, monthly mean temperature anomalies greater than +1.7°C were reported in northern Argentina and Uruguay, and anomalies greater than +1.4°C were found in November. During the spring (SON), positive anomalies were observed in the north and northwest of Argentina, where record high values were registered with respect to the last 50 years. In contrast, negative temperature anomalies on the order of -2°C characterized the climate of the Patagonia region during this season although the annual mean temperature remained from +0.5°C to +1°C above the climatological mean.

In Chile, very large anomalies, both positive and negative, characterized the temperature regime during 2009. The daily maximum temperatures during the austral summer were well above the climatological average, with mean anomalies of +2.3/+3.0 standard deviations for January/March, defining new records since 1914 at Santiago (33°S) and since 1961 for the region between 33°S and 37°S (Fig. 7.14). This behavior, associated with an anomalously intense subtropical anticyclone in the SE Pacific, persisted in the fall when anomalies close to +3.0°C were reported for the April mean daily maximum temperature in this region. In contrast, the 2009 austral spring (SON) was the coldest in the past 50 years in the region south of 37°S due to a large frequency of incursions of cold air masses from higher latitudes. This was particularly extreme during November, when anomalies from -2°C to -4°C were reported for the mean daily maximum temperature at stations between 35°S and 53°S, damaging the fruit ripening process in central Chile.

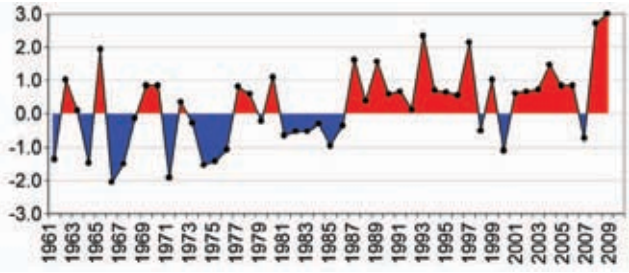


Fig. 7.14. Composite for standardized mean anomaly of daily maximum temperature along the subtropical west side of South America (Central Chile) for January–March, based on measurements at Santiago (33.5°S), Curicó (35.0°S) and Chillán (36.6°S). Standardization was done using 1971–2000. (Source: Dirección Meteorológica de Chile.)

(ii) Precipitation

During the first half of 2009, the exceptionally low precipitation in southeastern South America was driven by a La Niña episode, which began during the last quarter of 2007 and prevailed through 2008. La Niña gradually weakened during the first half of 2009. The positive SST anomalies that returned to the tropical Pacific Ocean by the middle of the year favored strong positive rainfall anomalies in southeastern South America during October–December 2009.

Large parts of eastern Argentina, Uruguay, Paraguay, and southern Brazil experienced a prolonged and intense drought during the first half of 2009, which caused severe damage to many socioeconomic sectors (agriculture, cattle farming, and hydro power generation). These conditions exacerbated the severe water shortage for the summer crops (soybean, maize, and rice) and pastures.

In particular, in Uruguay the mean rainfall deficit reached -20% during January–June, with values of -39% reported for the stations of Salto and Melo. In northern and northeastern Uruguay, rainfall returned to normal conditions in September. Exceptionally wet conditions followed in November, when monthly rainfall reached 613 mm in Artigas and 540 mm in Rivera (more than four times the monthly average) (DNM 2009). This heavy precipitation explains the fact that, although all months from January to August were drier than normal, the year ended with a positive rainfall anomaly of +31% in Uruguay.

In Argentina, the cumulative rainfall during 2009 was predominantly below the 1961–90 average. Deficits larger than -40% were observed in the Cuyo region, northeast of Patagonia, southeast of La Pampa, and north of Cordoba. In some cases the annual rainfall was the lowest since 1961. For example, the 369.1 mm measured at Pilar beat the previous record of 514.8 mm in 1962. Regarding anomalous wet conditions, above-average rains were registered in the northeast and east portion of the country (Iguazú +142% and +Gualeguaychú 149%) and also in the extreme northwestern territory and southern Patagonia (Bariloche +130%).

As in Uruguay, rains were markedly deficient in almost all the Argentinean territory until spring, giving continuity to an extremely dry period that had persisted since 2008, with important consequences for agriculture and livestock, water resources, and even some towns that had no water for consumption.

In spite of the El Niño conditions that persisted in the equatorial Pacific since May 2009, winter (JJA) rainfall in central Chile was near the climatological average, although it was characterized by a considerable intraseasonal variability at the monthly scale with May, July, and September being anomalously dry and June and August being anomalously wet. On the other hand, large-scale circulation anomalies linked to El Niño contributed to rainfall anomalies above +40% that were observed in the region 39°S to 46°S during the spring (SON).

(iii) Notable events in Argentina

The severe rainfall deficit of 2008 continued during almost all of 2009, mainly in the humid pampa and the west-central region. This reduction of rainfall not only affected the agriculture and cattle ranching, but also the lagoons and lakes.

On 2 February, a severe storm with heavy rains, high winds, and hail killed a dozen of people in the city of Rosario (second largest city in Argentina). On 8 February, local intense rain events generated landslides in Tartagal, Salta Province, northwestern Argentina, with 500 people evacuated and two deaths.

Between 21 and 23 July, a snowfall episode affected almost half the country, reaching an unusual intensity in some areas (south of Buenos Aires, La Pampa, and the eastern portion of Rio Negro).

During August, intense and persistent rainfall and snowfall episodes affected the western part of Mendoza and the provinces of Neuquén, Chubut, and Rio Negro (western and northwestern Patagonia Cuyo). During the same month, significant fires hit central Argentina (Cordoba and San Luis). A combination of lack of rainfall, high temperatures and strong winds made it difficult to control them.

During the night of 7 September, a category F4 tornado hit the district of San Pedro, leaving 10 people dead and 17 severely injured.

EXTREME RAINFALL IN NOVEMBER 2009 IN SOUTHEASTERN SOUTH AMERICA—M. BIDEGAIN, M. SKANSI, AND J.A. MARENGO

Portions of northern Uruguay, southern Brazil and northeastern Argentina experienced significant positive precipitation anomalies during November (Fig. 7.15). Northern and western Uruguay, Rio Grande do Sul (state in Brazil), and Entre Rios (province in Argentina) felt the impacts of the flooding that affected all cities along the lower basin of Rio Uruguay River. Estimates indicated that more than 5000 people were evacuated from Uruguay alone.

November 2009 was the wettest November in the last 30 years, since the Salto Grande dam was built (Fig. 7.16). Overall, more than 350 mm of rain felt in the region between 25°S–35°S and 50°W–60°W. The monthly average is 150 mm, but in some places the record exceeded 600 mm.

The National Institute of Meteorology of Brazil (INMET) and the National Institute for Space Research (INPE) reported that the November precipitation surpassed 400 mm at 19 meteorological stations of Rio Grande do Sul State, and average rainfall in all states was about 300 mm above normal. In Sao Luiz Gonzaga, the rainfall was 640 mm while the historical monthly average was 154 mm, a record for November since observations began in 1912.

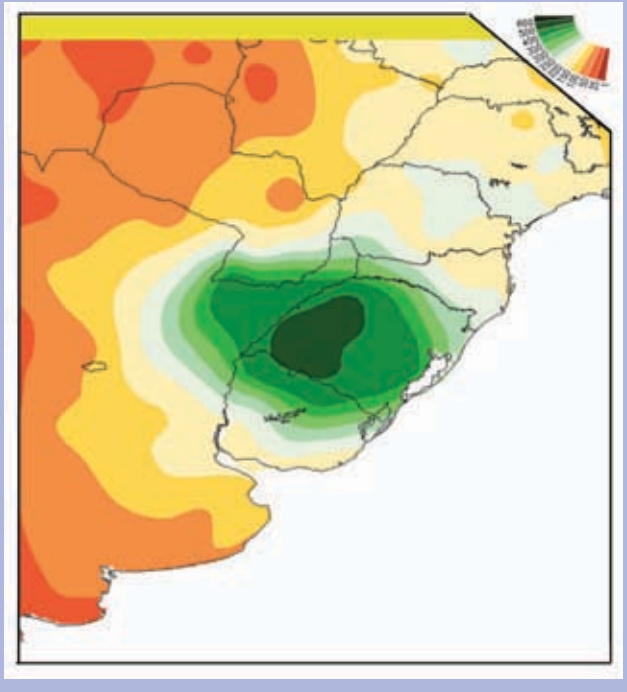


Fig. 7.15. November 2009 rainfall (mm) in southeastern South America. (Source: CPTEC/INPE.)

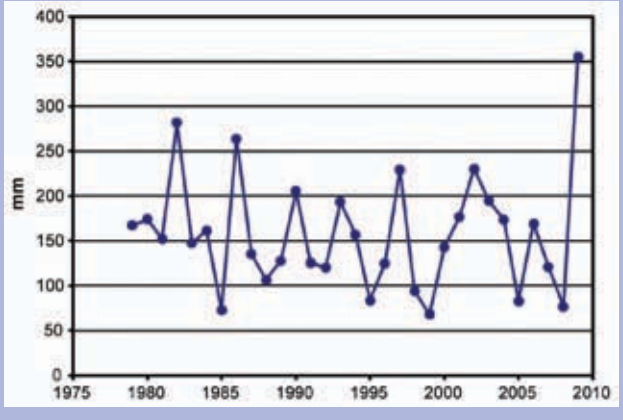


Fig. 7.16. November mean rainfall for southeastern South America, 1979–2009. (Source: GPCP.)

In November, there were exceptional rains in eastern Argentina, causing flooding and high levels of the Parana and Uruguay rivers. In many cities located over Rio Uruguay, people were evacuated (more than 5000 in Uruguay and 15 000 in Argentina. Excesses as large as 200% of normal rainfall and associated floods affected the southern and northern part of the Buenos Aires province (Gualeguaychú +334.8%, Laboulaye +246.8%, Junin +210.7%.), with the precipitation registered at Gualeguaychú (430 mm) and Laboulaye (377 mm) being the largest since 1940. San Antonio de Areco in the northern part of the province of Buenos Aires was the city with the most damage and evacuees.

e. Africa

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

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

(i) Temperature

In northwest Africa (Morocco, Algeria, and Tunisia), the annual mean temperature was mainly above normal in 2009, with the anomalies between +0.4°C and +2.5°C. Winter and autumn were exceptionally cold over the region with monthly mean minimum temperatures 0.1°C to 3°C below normal. January anomalies of -2.0°C and -2.2°C were found in Algeria and Morocco, respectively. Spring temperature

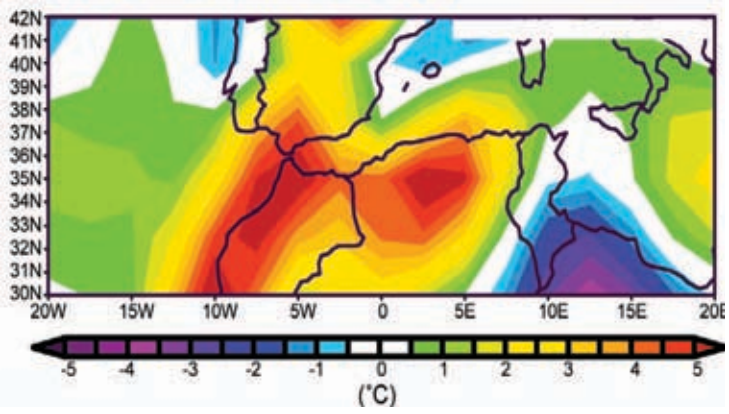


Fig. 7.17. Daily maximum temperature anomalies (°C) on July 21st 2009 for northwest Africa (based on 1968–96). (Source: NOAA/ESRL.)

reached 1.5°C above average over most parts of Morocco; the temperature ranged from 7°C in the north to 23°C in the south. During the summer, exceptional heat waves occurred. The monthly mean temperatures exceeded the normal; for example, the anomaly was +2.4°C in Tetouan in July. On 21 July, the daily maximum temperature reached between 47°C and 50°C in the Saharien City, Maskara in Algeria, Agadir, Tiznit, and Tan Tan in Morocco (Fig. 7.17).

In Egypt, 2009 can be described as a year with more stable and moderate weather than the previous years, with less temperature fluctuations and extreme events. For the 2000–09 decade, the annual mean temperature of Egypt remained above the normal by about 1.1°C. Fig. 7.18 shows a continued increasing trend from 1975. Only two years were below the average, 1982 and 1983. The warmest and second warmest years were 2008 and 2005 with anomalies of +1.9 and +1.7°C, respectively.

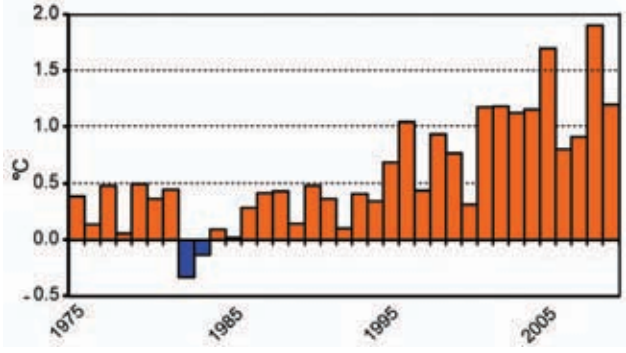


Fig. 7.18. Annual mean temperature anomalies (based on 1961–90) for Egypt, 1975–2009. (Source: Egyptian Meteorological Authority.)

(ii) Precipitation

In northwest Africa, annual 2009 precipitation was near normal to above normal. Large positive deviations also occurred in some regions and seasons, especially during the winter 2008/09 and the beginning of winter 2009/10, where rainfall was between 45% and 280% of average for most locations. Precipitation records during December 2009 represented 31% of the annual total. Many weather stations in Morocco, Algeria, and Tunisia reported rainfall exceeding 150 mm in less than 24 hours. Heavy storms that occurred from 20 to 25 December produced heavy rains causing floods. Rainfall amounts up to 200 mm in 48 hours were recorded, especially in the extreme north of Morocco. For example, Chefchaouen City recorded 834.9 mm in December for which the monthly normal is 265.4 mm (calculated from 1994 to 2000). The fall was variable spatially and temporally, but overall it was wetter than normal; October and November were considerably below average but September total rainfall exceeded the monthly mean by more than +800% in some areas of Morocco (for example in Rabat). In Tunisia, more than 90 mm was recorded in less than four hours at Zarzis, Gribis, and Souihel during the same month. Spring and summer were characterized by reduced rainfall activity over most of northwest Africa reaching more than 90% deficit, especially in August due to anticyclonic conditions.

In Egypt, the annual number of rainy days and the annual total precipitation for 2009 were near the historical average (based on 1961–90). The relative humidity was also around the historical average, with a variation range of ±5%.

(iii) Notable events

The year 2009 was characterized by heavy rainfall events, especially during winter, that affected Algeria, Tunisia, and Morocco. These events caused important infrastructure damages and human life loss in many cities and villages when many daily rainfall records for September and December were broken. Record wind speeds also occurred; for example, 140 km hr^{-1} in Khouribga City in May and 115 km hr^{-1} in Tangier in December. Several forest fires occurred in July and August, especially when the daily temperature exceeded 50°C for some locations in Algeria and 49°C in Morocco.

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

Western Africa is the region which extends from the Guinea coast and Côte d'Ivoire to Chad and the Central African Republic. The year was characterized by above-normal rainfall in the extreme western region, while dry conditions were found in the Côte d'Ivoire and Gabon areas.

(i) Temperature

January 2009 temperature anomalies (based on 1971–2000) were above normal with anomalies greater than 3°C in eastern Niger, western Chad, and part of northern Nigeria. The positive temperature anomalies continued in February, with anomalies greater than +3°C covering most of Niger, eastern Mali, northern Burkina Faso, and all of northern Nigeria. From March to June, the positive temperature anomalies decreased and became near normal in July, August and September. In October, the temperature once again became much above normal with anomalies reaching above +3.5°C over northern Niger. In November and December, the positive temperature anomalies continued over most of Western Africa. At Bilma, located in northern Niger, monthly mean temperatures were above normal for every month of the year (Figure 7.19). Negative temperature anomalies were almost nonexistent in the region, except in January when significant negative anomalies (less than -1.5°C) were observed over south Mauritania, western Mali, northern Guinea and Senegal.

(ii) Precipitation

In Western Africa, the rainfall anomalies (based on 1971–2000) showed significant deficits in April and May over Guinea, Liberia, southwest Côte d'Ivoire, and south Mali. In contrast, excessive rainfall was recorded over southeast Ghana, south Togo, southwest Benin, and parts of the central African countries. In June, rainfall deficits were observed over Guinea while heavy rains and floods hit most of the coastal settlements in the subregion.

In July, the Sahel rainfall increased with peaks ranging from150 mm–300 mm over western Senegal, the Gambia, and Guinea Bissau. The eastern Gulf of Guinea and northwestern part of the central African countries had a rainfall increase, with peaks ranging from 300 mm–400 mm over Nigeria and Cameroon.

In August, the peak rainfall for the Sahel ranged from 300 mm–400 mm over Burkina Faso, southern Mali, and southern Chad, intensifying to about 700 mm over Senegal and the Gambia and resulting in flooding. The southern Gulf of Guinea had a rainfall deficit. Above-normal rainfall was observed over the central African countries with peaks ranging from 300 mm–500 mm, intensifying to about 600 mm over Guinea Bissau, Guinea, and Sierra Leone.

In September, the rainfall in the Sahel generally decreased, but high accumulations ranging from 250 mm–500 mm were observed over central Burkina Faso, southern Mali, and Senegal. The Gulf of Guinea countries observed, similarly, a general decrease in rainfall, but observed high amounts of about 400 mm over Guinea Bissau, Guinea, and Nigeria spreading over parts of the central African countries.

Compared to the base period 1971–2000, July, August, and September 2009 had significant positive rainfall anomalies with severe rainfall deficits over most of the Gulf of Guinea countries and central African countries (Fig. 7.20). Positive rainfall anomalies were found in September with the maximum amount observed over south Mauritania, Senegal, Gambia, and central and western Mali.

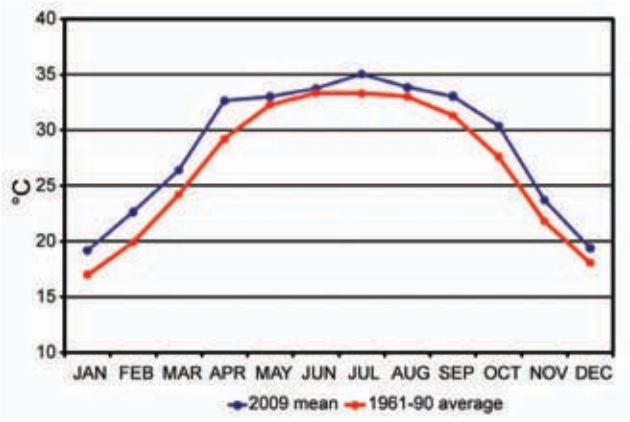


Fig. 7.19. Monthly mean temperature in 2009 and 1961–90 average for Bilma, Niger. (Source: African Centre of Meteorological Applications for Development.)

(iii) Notable events

According to UN Integrated Regional Information Networks (IRIN) 9 October report, more than 60 schools in Senegal were flooded due to the heavy rains in July, August, and September. The spokesperson for Senegal's Interior Ministry confirmed a $4.5 million U.S. emergency plan to pump out the water from flooded zones, rid standing water of mosquito larvae, and provide free health services at medical posts set up in affected areas.

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

The Great Horn of Africa (GHA) region can be divided into three main sectors. The northern sector

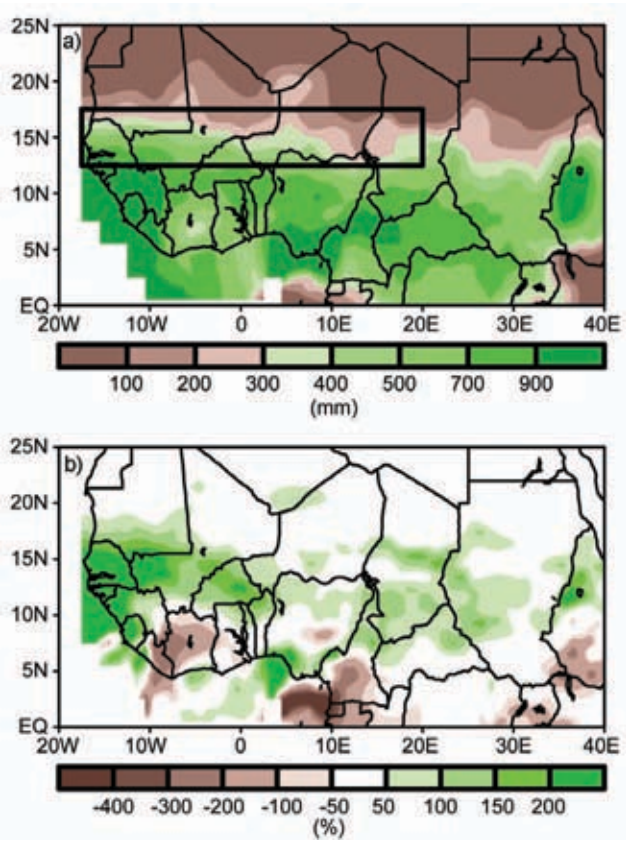


Fig. 7.20. (a) July to September 2009 rainfall (mm) for Western and Central Africa and (b) July to September 2009 anomalies (expressed as percentage of 1971–2000.) (Source: NOAA/NCEP.)

covers Sudan, Ethiopia, Eritrea, Djibouti, and northern Somalia; the equatorial sector includes Uganda, Kenya, Burundi, Rwanda, southern Somalia, and northern Tanzania; and the southern sector refers to central and southern Tanzania. The base period is 1961–90.

(i) Temperature

Overall, the temperature was warmer than average over most of the GHA. In June, the minimum temperatures were warmer than normal over western and northern Sudan; localized parts of western, central, and southern Ethiopia; coastal parts of Kenya; and eastern Tanzania. They were cooler than average only over a smaller area including central Somalia and southeastern Ethiopia. During the same month, the maximum temperatures followed a similar pattern; however, the below-average area was larger, extending to south Somalia and eastern Kenya. The patterns of above-average maximum and minimum temperatures in western and central GHA and of below-average maximum and minimum temperatures in the east were generally found throughout the year.

(ii) Precipitation

December to February marks the main rainfall season over the southern sector and the hottest season over the equatorial sector. During December 2008–February 2009, most of the northern and equatorial sectors received less than 75% of their long-term average (Fig. 7.21a). Isolated small areas over southern

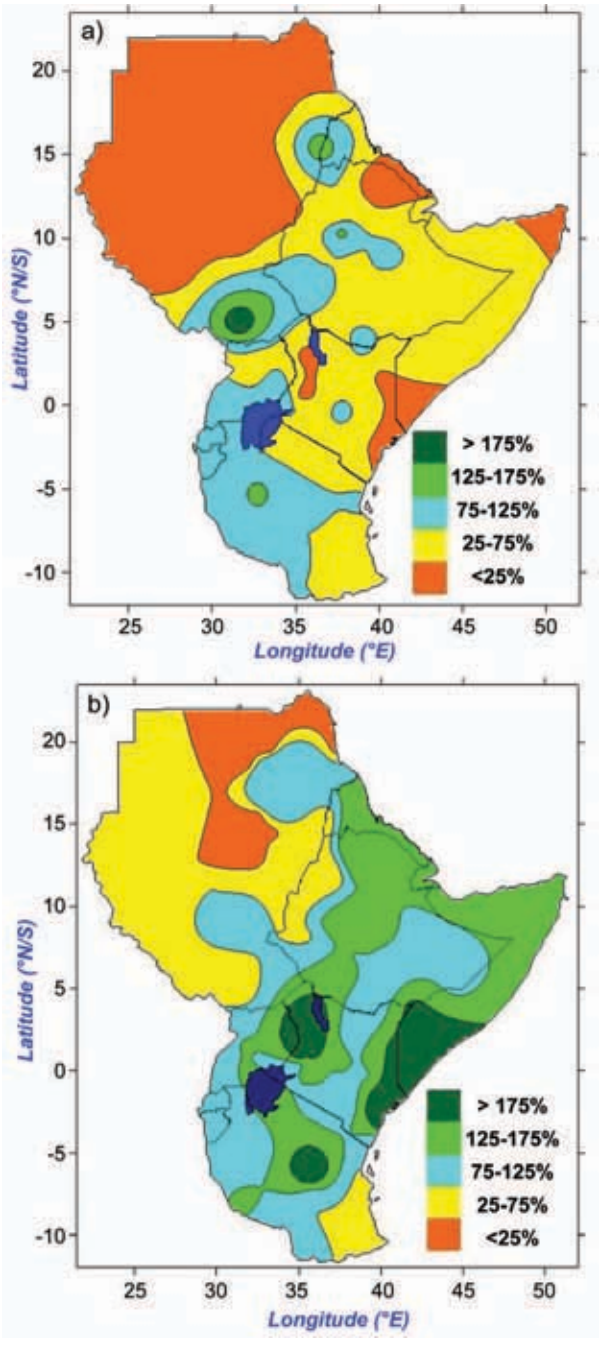


Fig. 7.21. (a) December 2008 to February 2009 rainfall anomalies and (b) October to December 2009 rainfall anomalies (expressed as percentage of 1961–90) for the Great Horn of Africa. (Source: ICPAC, 2009.)

and eastern Sudan, western and central Ethiopia, western Eritrea, central Kenya, and central Tanzania received more than 75% for the period.

March to May (MAM) is the main rainfall season over the equatorial sector. The onset of the MAM 2009 seasonal rainfall was rather late and the ending early. The western areas of both southern and equatorial sectors received 75%–125% of their long-term average. The rest of the GHA received less than 75% of their long-term average. The poor rainfall distribution resulted in crop failure and loss of livestock and wildlife due to drought conditions.

June to August is the main rainfall season over the northern sector and also the coldest period over the equatorial sector. The western parts of the equatorial sector received substantive rainfall over this period. The northern sector and northern parts of the equatorial sector received less than 75% of their long-term average. Localized areas over northern Uganda, northern and central Ethiopia, and central Sudan received near-normal precipitation.

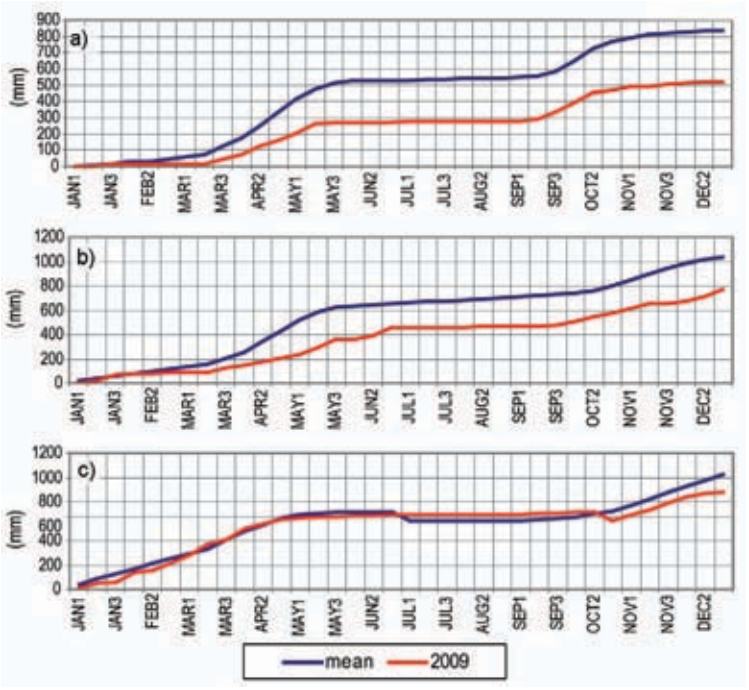


Fig. 7.22. Cumulative rainfall for (a) Neghelle, Ethiopia, (b) Dagoretti, Kenya and (c) Kigoma, Tanzania. (Source: ICPAC, 2009.)

September to December marks the second rainfall season (short rainfall season) over the equatorial sector. GHA, especially the equatorial sector, has one of the strongest climatic signals of ENSO events in terms of rainfall. The onset of ENSO for the short rainfall season was timely. However, over several locations, the distribution was not uniform with prolonged periods of dryness immediately followed by the onset of the rainfall season. Much of the GHA received between 75% and 125% of their long-term average, with eastern and northwestern Kenya, southern parts of Somalia, and central Tanzania receiving more than 175% of their long-term average (Fig. 7.21b). Episodic rainfall events towards the end of the period resulted in localized flooding in several parts of the central equatorial sector.

Fig. 7.22 compares the cumulative 10-day rainfall totals for 2009 with their long-term average. Neghelle, in southern Ethiopia, represents northern sector; Dagoretti, in central Kenya, represents equatorial sector; and Kigoma, in western Tanzania, represents the southern sector. The figure shows the rainfall deficit in the northern and equatorial sectors and adequate rainfall in the southern sector. The rainfall deficits resulted in cumulative climate stress which had both direct and indirect impacts on the climate-dependent sectors. Such impacts that were observed in 2009 include loss of livestock due to inadequate pastures, crop failure resulting in food insecurity, scarcity of the water resources resulting in rationing of hydropower and limited water for domestic and industrial uses, poor health resulting from malnutrition, and contamination of the water sources among other socioeconomic challenges.

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

This region includes the countries south of 15°S with more focus on South Africa and Zimbabwe.

(i) Temperature

For South Africa, the annual mean temperature anomalies for 2009, based on 27 climatological stations, was about 0.4°C above the reference period (1961–90). This made 2009 the 15th warmest year since 1961. Fig. 7.23 shows that the past 13 years were all above normal. For Zimbabwe, the temperatures were near normal with no records broken throughout the year.

(ii) Precipitation

The mean rainfall of South Africa is temporally and spatially very diverse. The main features are the fairly regular decrease in rainfall from east to west and also the marked influence of orographic features

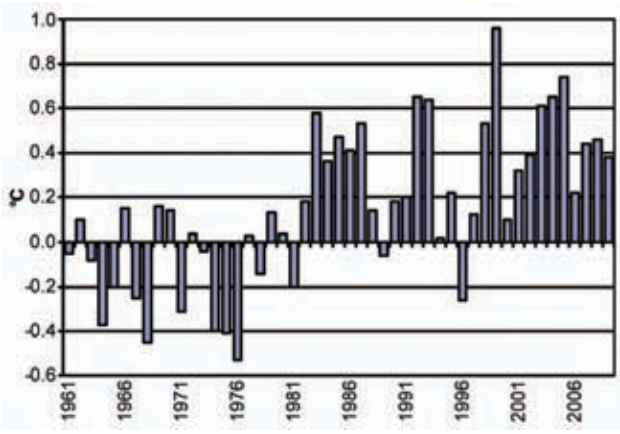


Fig. 7.23. Annual mean temperature anomalies (based on 1961–90) average over 27 stations in South Africa, 1961–2009. (Source: South African Weather Service.)

on the rainfall. The latter is most pronounced over the northeastern escarpment, the area around the northern border with Lesotho, and the southwestern and southern Cape. The average annual rainfall over the coastal plateau of the southwestern Cape is about 400 mm but in the mountains it ranges to more than 2000 mm in some locations. Although it is clear that there is a relationship between rainfall and elevation, other factors such as distance from the sea, rain-bearing winds, and type of rainfall (convective or frontal) also play a role.

The 2009 rainfall anomalies (Fig. 7.24) reflected the mean rainfall pattern, as most places in South Africa measured 75%–150% of the 1961–90 average. The most notable exception was the south and south-eastern coast and adjacent interior, which received mainly less than 75% of its annual mean.

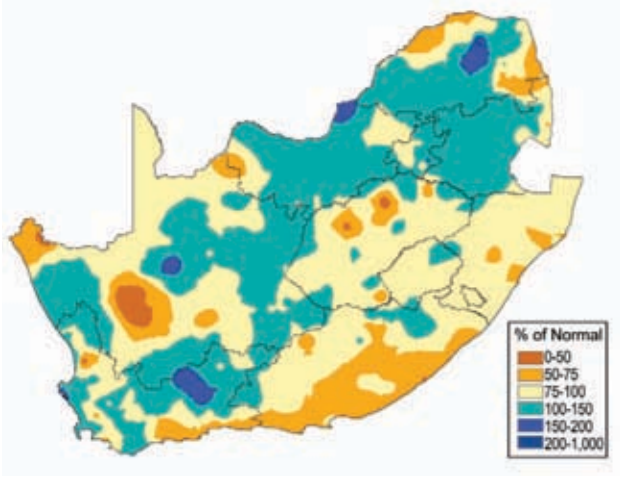


Fig. 7.24. Rainfall anomalies (expressed as percentage of 1961–90) for South Africa for 2009. (Source: South African Weather Service.)

For Zimbabwe, the rainfall season, from November 2008–March 2009, was characterized by normal to above-normal rainfall in most parts of the country. Rainfall amounts were generally moderate with no outstanding daily totals. The last two weeks of the season were very dry across the whole country. Overall, the December 2008–February 2009 rainfall anomalies for Southern Africa were near normal (Fig. 7.25).

(iii) Notable events

On 2 January, 45 families were left homeless when a storm accompanied by strong winds destroyed areas of Taung in the northwest. Villages that were affected include

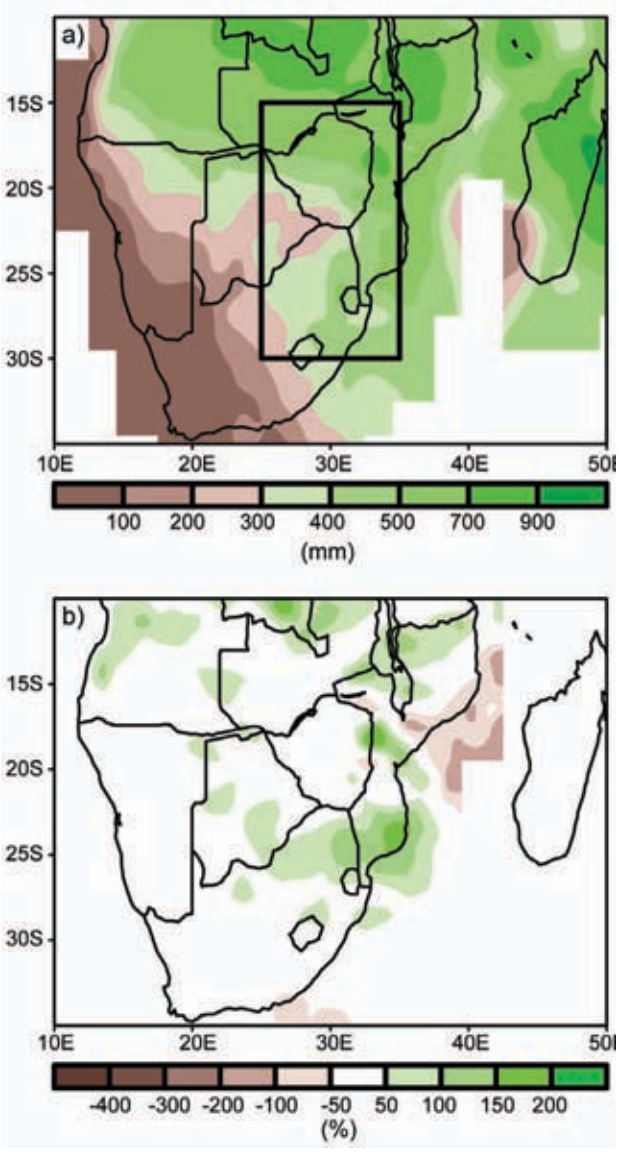


Fig. 7.25. (a) December 2008 to February 2009 rainfall (mm) for Southern Africa and (b) December 2008 to February 2009 anomalies (expressed as percentage of 1971–2000). (Source: NOAA/NCEP.)

Vergenoeg, Molelema, Kokomeng, and Longaneng. The storm left more than 500 people homeless and disaster management had to provide the affected families with blankets, mattresses, food parcels, and tents. The damage was estimated at more than R2 million ($264 000 U.S.).

A man died in his sleep when his mud hut collapsed on him during heavy rains at Mohlabaneng village in the Limpopo Province on 5 January, and 123 villagers were injured when their houses collapsed. Three hundred houses were destroyed and more than 1500 people were left homeless in the storm. The affected villages include Jamela, Mohlabaneng, Phaphadi, and Shawela.

Heavy rain that fell over the northern coastal areas of KwaZulu-Natal during the weekend of 7 March claimed the lives of at least five people and flooded hundreds of houses. KwaDukuza was also left without water after their water pumps and the pumps of the reservoir at Gledhow (which are used in emergency situations) were washed away. All rivers in the KwaDukuza area burst their banks causing extensive damage to houses in all 20 wards of the municipality.

Nearly 500 houses, affecting more than 1700 people in 28 informal settlements in Cape Town, were flooded during the weekend of the 16–17 May when the first of the annual Cape winter storms with intermittent rain and strong winds hit the Western Cape. Swells of about nine meters also occurred along the coastal regions.

Thousands were left homeless after heavy rains on 12 July caused flooding in the Western Cape, while rock- and mudslides caused damage to the infrastructure. The Lourens River in Strand and the Liesbeek River outside Cape Town burst their banks adding to the flooding problem. The Cape Flats seemed to be worst hit with people from 20 informal settlements having to be housed in community halls. About 9000 people from 2500 shacks were left homeless but there were no injuries reported. In Grabouw, 143 people had to leave their flooded homes while about 19 families from Jamestown and about 25 families near Cloetesville in Stellenbosch had to be evacuated because of rising flood waters.

Kimberley was hit by two heavy storms on 3–4 November causing extensive damage to houses, cars, and businesses; uprooting trees; ripping off roofs; and flooding several streets. The storms struck across the Northern Cape, including areas of Barkly West, Kuruman, and Longlands. Hundreds of houses were flooded in Galeshewe and some were completely washed away as water ripped through the low-lying areas of these informal settlements. An ecological disaster occurred at the swamped Kamfers Dam outside Kimberley where the third breeding season of the small flamingos started about a month earlier. Hundreds of both chicks and eggs were lost. This is one of four breeding spots in Africa and one of six in the world.

Hundreds of families were left homeless after heavy rains accompanied by golf ball-sized hail and strong winds affected Newcastle in northern KwaZulu-Natal on 11 December. Another storm hit the area seven days earlier and left 300 homes flattened. Six hundred families were left homeless after roofs were blown away, trees uprooted, and livestock destroyed in a damage estimated at millions of rands (hundreds of thousands of U.S. dollars). The municipality provided the victims with tents and food parcels. There were no injuries or deaths reported in both the storms.

5) Western Indian Ocean countries—L. A. Vincent, E. Aguilar, M. Saindou, A. F. Hassane, G. Jumaux, D. Schueller, P. Booneeady, R. Virasami, L. Y. A. Randriamarolaza, S. Andrianiafinirina, V. Amelie, and B. Montfraix

The analysis for the Western Indian Ocean countries is included for the first time in the *State of the Climate* report. This region is made of many islands grouped into five countries, namely République des Comoros, République de Madagascar, Republic of Mauritius, La Reunion (France), and République des Seychelles. Overall, the 2009 land surface temperature was well above normal (relative to 1971–2000) at most locations (Fig. 7.26a), while precipitation was generally near or slightly below normal (Fig. 7.26b).

(i) Temperature

In Comoros, the 2009 temperature was above normal every month with the exception of April when it was slightly below normal; the annual anomaly was +0.4°C. For Madagascar, the monthly mean temperatures were also near normal to above normal resulting in an above-normal annual mean temperature across the country (Fig. 7.27a). The highest monthly anomaly was +2°C observed in the northwest in October. The April temperature was also slightly below normal with a departure of -1.1°C in the south highlands. For the Republic of Mauritius, the 2009 temperature was above the 1971–2000 average by 1.0°C for Mauritius, 0.8°C for Agalega, and 0.6°C for Rodrigues islands. Every month stayed above normal at these locations except for Rodrigues when the temperatures were slightly below normal from July to September. For

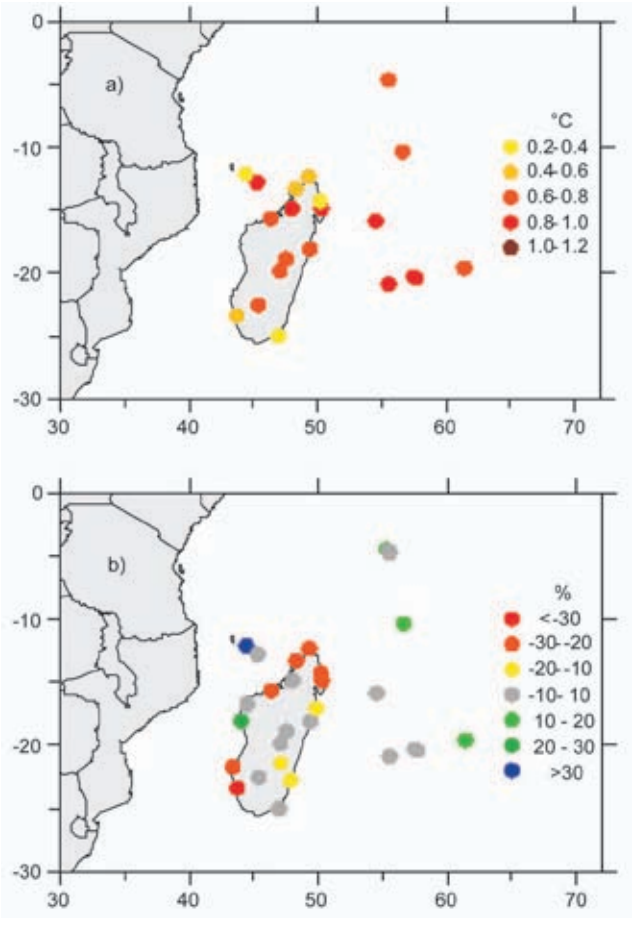


Fig. 7.26. (a) Annual mean temperature anomalies (°C; based on 1971–2000) and (b) annual precipitation anomalies (% of 1971–2000) for the countries of the Western Indian Ocean for 2009. (Source: Météo Nationale Comorienne, Service Météorologique de Madagascar, Météo-France, Mauritius Meteorological Services and Seychelles National Meteorological Services.)

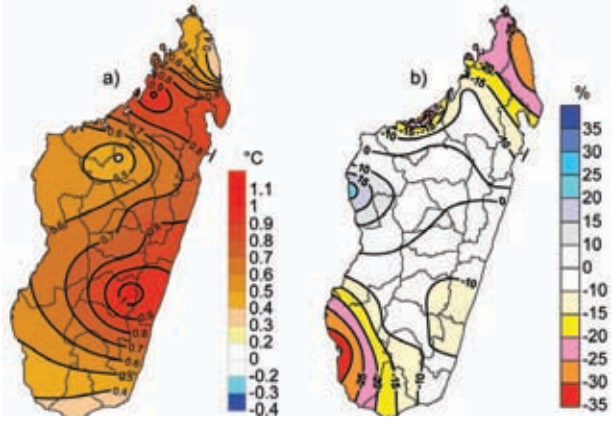


Fig. 7.27. (a) Annual mean temperature anomalies (°C; based on 1971–2000) and (b) annual precipitation anomalies (% of 1971–90) in Madagascar for 2009. (Source: Service Météorologique de Madagascar.)

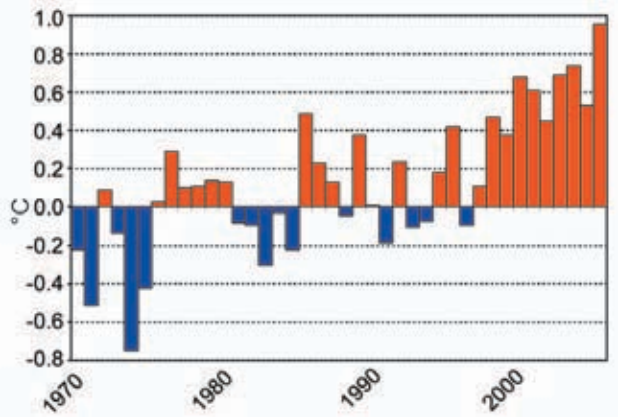


Fig. 7.28. Annual mean temperature anomalies for La Reunion (average of 10 stations observations), 1970–2009. (Source: Météo-France.)

La Reunion, 2009 was the warmest year since 1970 (Fig. 7.28) with an anomaly of +0.95°C (+0.84°C for minimum temperature and +1.07°C for maximum). Fig. 7.28 shows that the temperature has been above the 1971–2000 average for 10 consecutive years, with 8 of the warmest 10 years occurring in the last decade. For Seychelles, above-normal temperatures occurred every month with the exception of February. The annual anomaly was +0.6°C.

(ii) Precipitation

For Comoros, the 2009 annual total anomaly was +41.2% even though rainfall was below normal for nine months. April was very wet, as more than 1700 mm of rain was observed in 23 days. For Madagascar, the annual total was mainly near normal while some small regions in the north and south had below-normal precipitation (Fig. 7.27b). The accumulated annual rain over Mauritius, Agalega, and Rodrigues islands was near normal or slightly above normal. However, October 2009 was the wettest October on record in Mauritius with 250% of the long-term average (1971–2000). For La Reunion, the annual anomaly was +10% over the island (13th wettest year since 1970) although a contrast of -19% in the west to +53% in the southeast was observed. April was also a very wet month in La Reunion. The annual total precipitation was generally near normal for Seychelles.

(iii) Notable events

April 2009 was marked by significant heavy rainfall in Comoros, Madagascar, Agalega (part of Republic of Mauritius), and La Reunion. This was due to Tropical Storm Jade, which appeared on 5 April. Wind gusts of 170 km hr^{-1} were observed on the east coast of Madagascar and heavy precipitation led to

several floods. More than 100 houses were flooded in southeast La Reunion.

Heavy precipitation was also observed in July in Comoros and Seychelles. Although it brought landslides and flooding in Seychelles, the rain was a relief for the country since it was experiencing very dry conditions and government-imposed restrictions on water use. The increase in precipitation was associated with an easterly wave which brought more than 150 mm of rain over a time period of 12 hours. This type of weather is rare in Seychelles.

f. Europe

1) Overview—A. Obregón, P. Bissolli, J. J. Kennedy, and D. E Parker

Widespread anomalous warmth affected much of continental Europe in 2009. The annual-average land surface air temperature anomaly from the CRUTEM3 dataset (Brohan et al. 2006), relative to 1961–90, was +1.05[1]±0.07°C for the European region (35°N–75°N, 10°W–30°E). This ranked 2009 as between the third and tenth warmest year since 1850, with a nominal ranking of seventh. Notably, 2000–09 was the warmest decade on record for Europe, with an anomaly of +1.0±0.12°C, significantly warmer than previous decades (1990s: +0.58±0.11, 1980s: +0.06±0.10).

The highest temperature anomalies of 2009 were recorded in the Mediterranean countries, Eastern and parts of Central Europe, Fennoscandia (Norway, Sweden, Finland) and the Arctic region (including Iceland and Greenland), all with annual mean temperature anomalies in the range from +1°C to +2°C (Fig. 7.29). Svalbard (Arctic Norway), which has recorded the highest anomalies in greater Europe in recent years, again exceeded +2°C.

Total precipitation for the year 2009 (Fig. 7.30; Schneider et al. 2008) was above average over most of Eastern and Southeastern Europe, Ireland, northern and southern parts of the UK, Iceland, and in parts of Fennoscandia. It was particularly wet in Austria, where new record annual precipitation totals were set in several places, and in Belarus. Drier-than-average conditions occurred over the Low Countries (Netherlands, Belgium, and Luxembourg), western parts of Germany, much of France and central parts of England, where totals were 80%–100% of normal. Some smaller parts of Iberia, southern France, Scandinavia, Russia, the Middle East, and Greenland received rainfall totals below 80% of the long-term average over the year 2009.

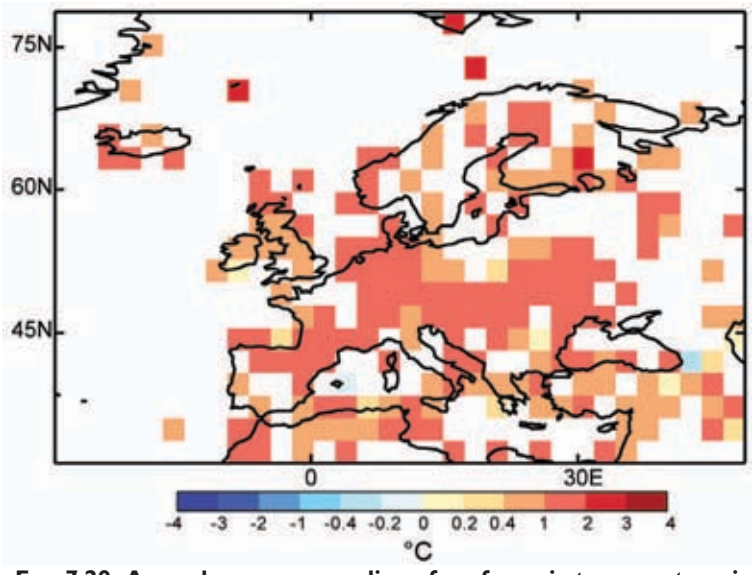


Fig. 7.29. Annual mean anomalies of surface air temperature in Europe and over the North Atlantic, 2009 (°C, 1961–90 base period), CRUTEM3 data updated from Brohan et al. 2006. (Source: UK Met Office.)

The year commenced with below-average 500-hPa heights over Southern Europe and large positive anomalies over Fennoscandia and Russia (Fig. 7.31, DJF). This large-scale circulation mode is similar to the Eastern Atlantic/Western Russia pattern (Barn-

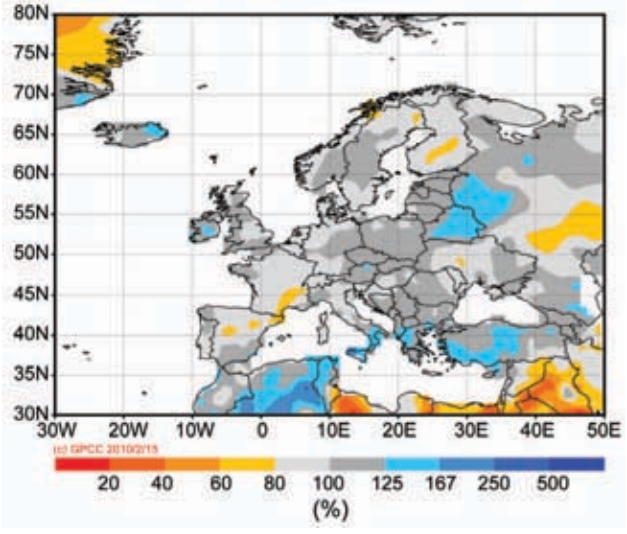


Fig. 7.30. European precipitation totals (% of normal, 1951–2000 base) for 2009. (Source: Global Precipitation Climatology Centre [GPCC], Schneider et al. 2008.)

[1] The standard reference period used for European averages is 1961–90 for temperature and 1951–2000 for precipitation, unless otherwise expressly identified.

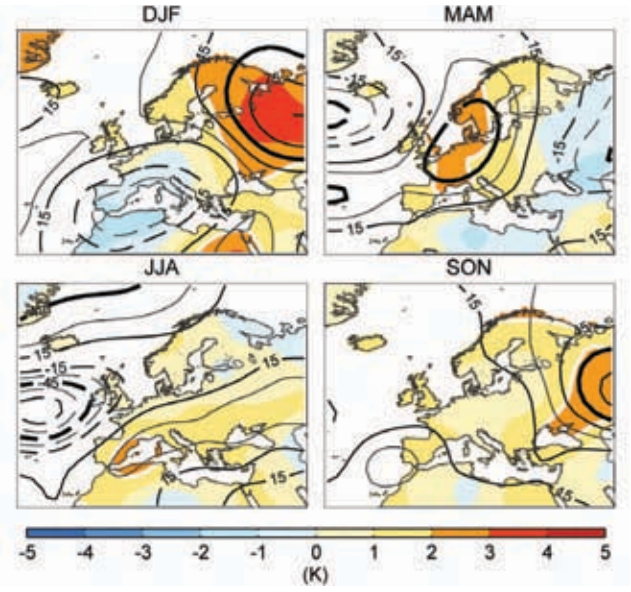


Fig. 7.31. Seasonal anomalies (1961–90 reference) of 500 hPa geopotential height (contour, gpm) and 850 hPa temperature (shading, K) using data from the NCEP/NCAR reanalysis. (DJF) winter (Dec 2008–Feb 2009), (MAM) spring (Mar–May 2009), (JJA) summer (Jun–Aug 2009) and (SON) autumn (Sep–Nov 2009). Black (white) thick lines highlight those geopotential height (temperature) contours with all the encircled grid points having absolute anomalies above their 1-sigma level of the base period.

ston and Livezey 1987). As a consequence, western and southwestern parts of Europe were significantly colder than normal (Fig. 7.32a), with monthly mean anomalies during January as low as -3°C in France and parts of Germany. Southern and Southeastern Europe experienced above-average precipitation (Fig. 7.33, DJF) and increased winter storm activity. In contrast, mild temperatures prevailed over Eastern Europe during winter 2008/09 with peak anomalies > +4°C in northwest Russia and Finland. Spring was very warm, particularly in Western and Central Europe (Fig. 7.32b), largely due to an anomalous ridge of high pressure which remained dominant throughout the season (Fig. 7.31, MAM). Temperature anomalies peaked during April, when they exceeded +5°C in places in Germany, Austria, and the Czech Republic (Fig. 7.34). Mean temperature records for April were broken in several locations.

Summer was also warmer than normal over Europe, though with smaller anomalies than spring (Fig. 32c). This was largely the result of a dipole pattern of near- to below-average 500-hPa height anomalies over the Atlantic and Fennoscandia, and above-average 500-hPa heights over the Mediterranean and Southern Europe (Fig. 7.31, JJA). Consequently, above-average precipitation was observed across Northwestern Europe and Fennoscandia (Fig. 7.33, JJA), and above-average temperatures were observed across Southern Europe with anomalies exceeding +2°C in southern France and Spain (Fig. 7.32c). A heat wave affected Italy in July, with temperatures locally reaching 45°C, while Iberia also experienced several heat waves during the summer. Some stations in Norway reported new daily maximum temperature records. Western and Central Europe were affected by severe thunderstorms, accompanied by heavy rain and hail, causing local flooding.

Autumn temperatures were well above average across Europe, particularly in the central and eastern regions (Fig. 7.32d). Precipitation showed extreme temporal and spatial variation during autumn (Fig. 7.33, SON). Positive 500-hPa height anomalies across Northern Europe and a broad trough across Southern Europe during September (Fig. 7.31, SON) were associated with above-average temperatures across much of Europe and western Russia. Southern Europe and the Mediterranean experienced very high precipitation totals (Fig. 7.33, SON). October precipitation was exceptionally high in Eastern and Southeastern Europe, and October temperatures were low in Scandinavia and Northeastern Europe. During November, an extensive flow of marine air into the European continent resulted in generally above-average temperatures with the largest departures in Fennoscandia

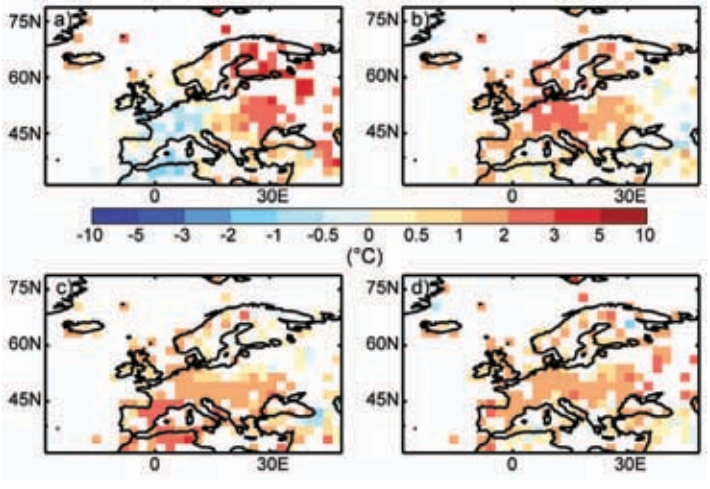


Fig. 7.32. European land surface air temperature anomalies (°C, 1961–90 base period), CRUTEM3 updated from Brohan et al. 2006. (a) December 2008 to February 2009; (b) March to May 2009; (c) June to August 2009; (d) September to November 2009.

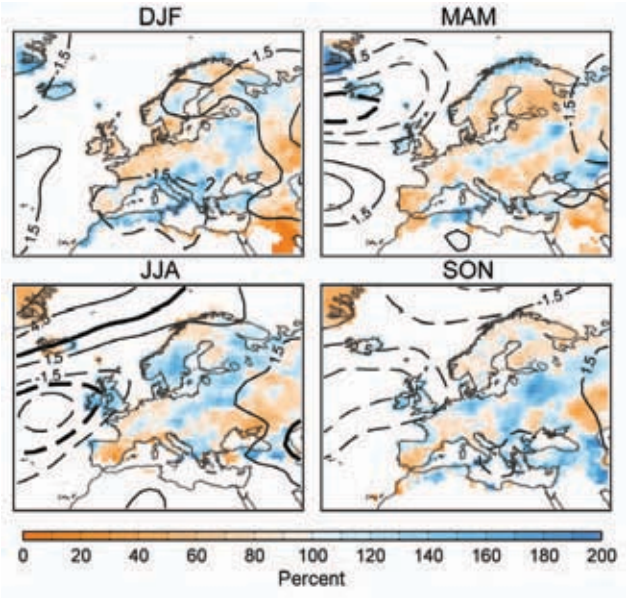


Fig. 7.33. Seasonal anomalies, with respect to the 1961–90 mean, of sea level pressure (hPa) from NCAR/NCEP reanalyses. Colored shading represents the percentage of accumulated seasonal precipitation compared with the 1951–2000 climatology from the seasonal GPCC precipitation data set (only values above 15 mm per season are represented). Thick black lines highlight those sea level pressure anomalies which are greater than one standard deviation above the mean.

and western Russia, where temperature anomalies exceeded +3°C. Increased cyclonicity led to well-above-average November precipitation, particularly in the northern half of Europe with new records set across Ireland and the UK.

The end of the year was characterized by an extremely negative phase of the Arctic Oscillation (AO) with high pressures dominating the higher latitudes of the Northern Hemisphere, affecting the weather in Europe. The AO Index in December 2009 was -3.4, the lowest value observed for that month in 60 years (Fig. 2.30b in Section 2d), with extremely negative values in the second half of the month. Most of Europe was under the influence of a strong high pressure system over the Arctic and Scandinavia that favored intense advection of cold polar air far into the middle latitudes (Trigo et al. 2004). The negative North American Oscillation index in December also contributed to a starkly contrasting temperature pattern over Europe. While Southeastern Europe and parts of the polar region (Greenland, Iceland, Svalbard) experienced mild temperatures—Greenland was 7°C warmer than average—colder-than-average conditions prevailed over the northern half of Europe with heavy snowfall in places. The Scandinavian high pressure also caused a dry December in Northern Europe, while most of the rest of Europe, particularly the South, experienced a very wet end of the year.

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

Countries considered in this section include: Ireland, the United Kingdom, the Netherlands, Belgium, Luxembourg, France, Germany, Switzerland, Austria, Poland, Czech Republic, Slovakia, and Hungary.

(i) Temperature

Annual mean temperatures in Central Europe were 1°C–2°C above the 1961–90 average throughout most of the region (Fig. 7.29). Over Western Europe, anomalies were mostly below +1°C.

Winter 2008/09 was the coldest in the UK since 1996/97. In France, it was the third coldest winter in 20 years. Severe cold waves during January and February brought temperatures below -25°C to Germany and Poland. The lowest recorded daily minimum temperature in 2009 in Poland was -28.2°C in the southwest of the country on 7 January. A private weather service station in Saxony, eastern Germany, recorded -29.1°C on the same day. In contrast, winter was warmer than average in the easternmost regions (Poland, Czech Republic, Slovakia, Austria, and Hungary; Fig. 7.32a).

Spring temperatures were well above average, mainly due to an exceptionally warm April (Fig. 7.34). Belgium and Switzerland each reported their second warmest spring on record. April was the second warmest on record for De Bilt in the Netherlands

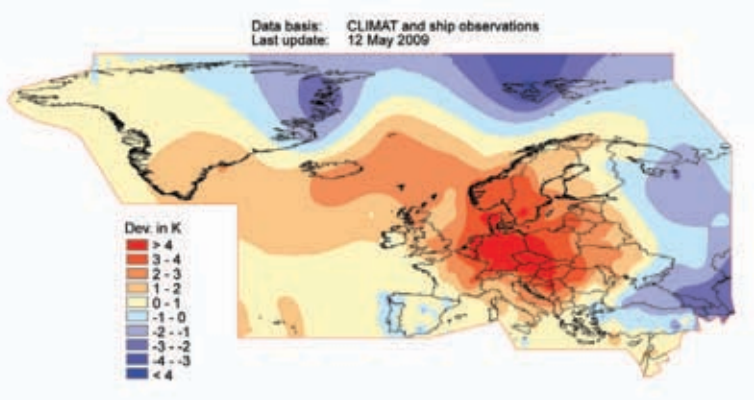


Fig. 7.34. Monthly mean anomalies of surface air temperature across Europe and over the North Atlantic, April 2009 (1961–90 base period) based on CLIMAT and ship observations. [Source: Deutscher Wetterdienst (DWD).]

(1706–2009), and new national records were set for mean anomalies in Hungary (+4.2°C) and Germany (+4.5°C; 1901–2009).

Summer temperatures were generally above average (Fig. 7.32c), most notably in southern France and Switzerland where anomalies were more than +2°C. A significant heat wave affected Western Europe during July, while a heat wave in France from 15–20 August resulted in temperatures above 36°C in the North and 40°C in the South.

Monthly mean temperatures for November were among the three warmest in the last century across the United Kingdom, Netherlands, Belgium, France, and Germany. In southern Germany, maximum temperatures of around 20°C were reached as a result of foehn winds; such high temperatures are unusual during November.

December was cold especially in the UK and Ireland but also in northern Central Europe and on both sides of the Alps, with anomalies below -1°C. This was mainly due to a long cold spell in the second half of the month.

(ii) Precipitation

Annual precipitation amounts were normal or above normal in Central Europe (Fig. 7.30), though some regions in southern France received only 70–80% of their normal totals. The United Kingdom and Ireland experienced a wet year. Valentia Observatory in Ireland reported its highest annual rainfall total since records began in 1866.

Winter was mainly dry throughout Central and Western Europe (around 60%–80% of normal, Fig. 7.33, DJF), but with heavy snowfall in some areas particularly during February. In February and March, heavy snowfall in parts of the northern Alpine region resulted in peak snow depths of over four meters.

It was the driest spring since 1997 in England and Wales, while March was exceptionally wet in eastern Central Europe; the Czech Republic reported almost double its average March rainfall. April was very dry in eastern Central Europe. Hungary recorded only 23% of its average 1971–2000 April rainfall, while Poland experienced rainfall in the 10th percentile of its 1961–90 distribution.

England and Wales had their wettest July on record, while western Scotland had its wettest August since records began in 1910. This was the third consecutive wet summer in the UK and Ireland (Fig. 33, JJA). In Switzerland, the city of Lugano reported its highest July precipitation (397 mm) since records began in 1864, mainly due to two large thunderstorms during the middle of the month. In contrast, dry conditions in August and September prevailed over Western and Central Europe.

November was the wettest in recorded history across the UK and most of Ireland. The Alps had received intense snowfalls by the end of November. December again was a wet month in most of Western and Central Europe but very dry in Ireland and Scotland.

(iii) Notable events

A severe North Atlantic storm with strong winds up to 174 km hr^{-1} affected the UK and Ireland on 17 January. Another Atlantic storm, with gusts of hurricane force, affected Western Europe on 23–24 January. Southern Ireland saw heavy rain with severe flooding on 29–30 January.

Unusual snow events affected Western Europe at the beginning of the year. On 6–7 January, a Mediterranean storm dropped 20 cm–40 cm of snow across southeastern France for the first time since 1987. At the beginning of February, the United Kingdom experienced its most widespread snowfalls since 1991, resulting in peak snow depths of up to 30 cm. London received its heaviest snowfalls in 18 years. In the Alpine region, the snows lasted until the end of February even at low elevations, which was unusual, especially south of the Alps.

Various episodes of heavy rainfall occurred during summer. On 6 June and 16–17 July, the United Kingdom experienced daily totals of more than 90 mm. Likewise, heavy precipitation, flooding, and mudslides affected Central Europe on 21 June. On 2 July, Dublin was affected by flooding after torrential rainfall. A severe storm on 23 July affected Germany, Poland, and the Czech Republic.

Autumn also had some noteworthy heavy rain events with flooding. On 3 September in northeast Scotland, daily totals exceeded 120 mm. Parts of Aberdeen city centre were flooded with disruptions to roads and rail services. A frontal system moving across the Atlantic Ocean caused record precipitation and widespread flooding in northwestern England on 18–20 November (see sidebar). Central Europe experienced gusts of hurricane force on 23–24 November.

A severe cold spell and heavy snowfall 15–22 December affected most of the region. Temperatures below -20°C were reported in Germany and France. The Netherlands experienced unusually heavy snowfall, with snow depths up to 30 cm. Cold and snowy conditions continued into 2010.

SEVERE FLOODING IN NORTHWEST ENGLAND IN NOVEMBER 2009—M. KENDON AND J. PRIOR

Exceptionally prolonged and heavy rainfall on 18–20 November led to severe flooding across the Lake District in Cumbria (northwest England). Parts of the high ground received more than 400 mm in 72 hours. Seathwaite in Borrowdale recorded 316.4 mm in 24 hours, approaching its November average of 364.3 mm and setting a new UK record for any 24-hr period. The flooding problems were made worse by saturated ground conditions following wet weather earlier in the month. Many rivers in the Lake District exceeded their previous maximum flows by a wide margin and exceptionally high flows were also reported across north Wales and southern Scotland. Several road bridges collapsed or were damaged, and some 1500 properties were flooded, many in the town of Cockermouth. Cumbria last experienced serious flooding on 8 January 2005, when Carlisle was badly flooded by the River Eden.

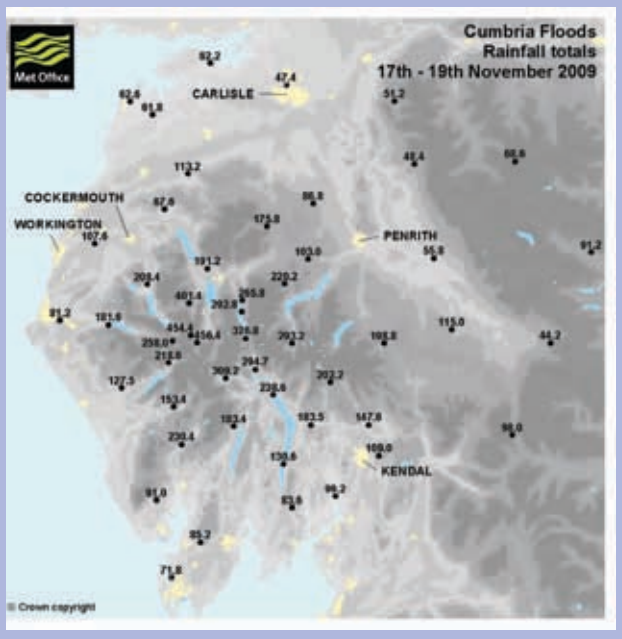


Fig. 7.35. Rainfall across northwest England from 0900 UTC on 17th to 0900 on 20th November 2009.

3) The Nordic and Baltic countries—C. Achberger, S. Hellstrom, J. Cappelen, S. Saku, K.A. Iden, T. Jonsson, A. Obregón, P. Bissolli, J.J. Kennedy, and D.E. Parker

Countries considered in this section include: Iceland, Norway, Denmark, Sweden, Finland, Estonia, Latvia, and Lithuania.

(i) Temperature

Mean annual temperatures in the Nordic Countries were above normal, with annual temperature anomalies ranging from +0.5°C to +1.5°C, except in the Arctic where they were higher. The highest positive anomalies were recorded in Svalbard, with mean temperatures 2°C–3°C above the 1961–90 average. In Iceland, Reykjavik reported its tenth warmest year since measurements commenced in 1870, while Denmark recorded its eighth warmest year since records began in 1874 with an anomaly of +1.1°C. Norway recorded a mean annual temperature anomaly of +1.0°C, ranking 19th since records began in 1900, with all seasons recording above-average mean temperatures. Throughout the Baltic countries, annual temperature anomalies also were around +1°C (Fig. 7.29).

A very mild winter 2008/09 prevailed everywhere except in the western Nordic countries, though February was cold over most of Fennoscandia. The highest departures, exceeding +4°C, were observed on Svalbard and in Finland (Fig. 7.32a). Anomalies in Denmark were +1°C, which was less than in 2007 and 2008 when anomalies exceeded +4°C.

Spring was exceptionally warm throughout most of the region (Fig. 7.32b). April was exceptionally warm (Fig. 7.34), with Denmark setting a new record mean temperature of 9.4°C, some 3.7°C above normal. In Norway, it was the third mildest April since 1900, with several stations in the South setting new monthly mean temperature records. In Sweden, April average temperatures were generally 1°C–4°C warmer than normal, and there were locations with monthly mean temperatures above 10°C, which has never occurred in Sweden during April since records began in 1860. The April mean temperature in Gothenburg was 10.4°C, beating former nationwide records. In contrast, April was the only month of the year with below-average temperatures on Svalbard (-3.7°C anomaly). In Longyearbyen, 22 April saw the coldest April temperature (-19.5°C) since 1993.

Summer and autumn were at least slightly warmer than normal across much of the Nordic and Baltic region (Fig 7.32c,d), particularly during August. However, the beginning of June and July was exceptionally

cold in southern and central Finland. Except for the Arctic, October was a cold month throughout Northern Europe with anomalies below -2°C in some areas.

The end of the year was exceptionally mild in the Arctic region, with anomalies at Svalbard airport of +8.4°C for November and +10.9°C for December. The rest of the region (with the exception of northern Finland and Iceland) experienced a colder-than-normal December with monthly mean anomalies below -1°C.

(ii) Precipitation

Total annual precipitation was generally near normal over the Nordic countries during 2009 (Fig. 7.30). While large parts of Sweden and areas in Denmark recorded rainfall above their 1961–90 average, only eastern Iceland received in excess of 125% of their 1951–2000 normal totals. Annual precipitation was below 80% of normal over northern Greenland and parts of northern Scandinavia.

Winter in Denmark was characterized by well-below-average precipitation, recording only 66% of its average total for the season (Fig. 7.33, DJF). In contrast, in Östersund, Sweden, a snow depth of 81 cm during February was the highest monthly depth recorded since March 1988.

Spring precipitation was more than 20% below normal in parts of Sweden and Denmark, southern Finland and across the Baltic countries. April was particularly dry in southeastern Sweden (in places the driest since 1974), with the region recording less than 5% of its 1961–90 average rainfall. In some locations, no measurable April precipitation was reported; the last month without any measurable precipitation in parts of Sweden was August 2002. It was also dry in the Baltic countries. In contrast, May was the second wettest on record in northern Norway, resulting in a nationwide mean rainfall value that was 165% of its 1961–90 average.

Summer was very wet over most of the region (Fig. 7.33, JJA). Rainfall in Denmark and Sweden was 15% above the 1961–90 long-term average. On 11–12 June, Sjælland in the eastern part of Denmark received more than double its monthly-normal rain within these two days. One station on Sjælland recorded 160 mm for the event. Likewise, Lithuania was significantly wet in June and July, while for many places in Norway and Sweden July was among the wettest since records began in 1900. Some areas of Sweden recorded up to 350% of their average July totals. Conversely, July and August were very dry in western Greenland; the station of Nuuk recorded its second driest July since 1890 with a total of only 1.4 mm. For Iceland, the first part of the summer (particularly June and July) was very dry in the southern and western part of the island. The summer was the driest for the capital, Reykjavik, since 1889. Similarly, the western part of Iceland suffered from the dry conditions. October was significantly wet in the Baltic countries, with 150% of the 1961–90 average in Latvia and Lithuania. November was wetter than average in southern Scandinavia and Denmark, where the 90th percentile of the 1961–90 distribution was exceeded. A new November record of 27 precipitation days was registered for Denmark as a whole.

December precipitation in Latvia was 140% of the 1961–90 normal. In Estonia, snow depths of 43 cm at the end of December set a new record snow depth for this month. In contrast, parts of the Norwegian west coast received < 40% of their December precipitation normal 1961–90 (some areas < 15%) owing to the infrequency of westerly airflow.

In Iceland, the number of days in 2009 when the ground was covered by snow was much lower than the 1961–90 normal (e.g., 40 days in Reykjavik compared to a normal of 65 days).

(iii) Notable events

The Nordic Region was hit by a number of significant and relatively rare summer storms that locally caused damage and even casualties.

A supercell thunderstorm hit the southern part of central Finland on 28 June. Storm downbursts caused extensive forest damage. Furthermore, extremely large hailstones with diameters up to 8 cm damaged buildings and cars.

On 30–31 July, an intense low pressure system formed over southern Norway generating very strong winds in Denmark, southern Sweden, and southern Norway. Wind speeds up to 101 km hr^{-1} were measured locally along the Danish and Swedish west coast. One ship sank outside the Swedish west coast causing the deaths of six people and a bulk freighter grounded in southern Norway causing an oil spill across a wide area.

In the middle of November, Denmark was again hit by a strong storm with wind gusts up to hurricane force (132.5 km hr^{-1}). A low-pressure system formed locally over the North Sea developing its full strength when passing Denmark on 18 November. The strong winds considerably raised the sea level along the Danish west coast, uprooted trees, and caused minor damage to buildings.

4) Iberia—R.M. Trigo, D. Barriopedro, C.C. Gouveia, A. Obregón, P. Bissolli, J.J. Kennedy, and D.E. Parker

Countries considered in this section include: Portugal and Spain.

(i) Temperature

The Iberian Peninsula registered significantly above-average temperatures for 2009 (Fig. 7.29). The annual mean anomalies for Iberia generally ranged between +1°C and +2°C, with higher values in the East. Large parts of the West recorded anomalies of between 0°C and +1°C. The year started with a negative anomaly for the winter (-0.72°C), followed by a warmer-than-average spring (+1.57°C), a particularly warm summer (+1.88°C), and a relatively warm fall (+1.26°C, Fig. 7.31). Several cold spells affected Iberia in January and February. Snowfall occurred even in low-altitude coastal regions of Portugal, which is an unusual phenomenon there, and new records in the number of snow days in Spain were reached for January, e.g., in León (14 days, highest since 1938, about 800 m elevation) and Ávila (11 days, highest for about 20 years, 1100 m elevation). The following seasons were generally characterized by high values of 500-hPa geopotential height, with maximum anomalies located north of Iberia (spring) and over eastern (summer) and western (autumn) Iberia.

It was the third warmest year in Spain since 1961 (anomaly +1.25°C relative to 1971–2000). The largest anomalies were observed in the central and southern regions, and in the northwestern Iberian Peninsula. The lowest deviations were restricted to the Balearic Islands. Temperature departures in Portugal were highest in the North (+0.9°C, 1971–2000 base) but generally lower than those anomalies in Spain (+0.5°C averaged over whole mainland Portugal). The warmest months of 2009 in Spain (relative to normal) were May, June, October, and November, when mean temperatures were more than 2°C above average. Overall, in Portugal the warmest months (relative to normal) were March, May, and October.

Winter 2008/09 temperatures were slightly below the long-term average. In contrast, much of the rest of the year was exceptionally warm (Fig. 7.32). Temperature anomalies in spring exceeded +2°C in the central Peninsula, while summer brought record mean temperatures (for the last 50 years) to many stations in Catalonia and to northern and central parts of the Peninsula. The summer and autumn anomalies for Spain including the Balearic Islands were +1.9°C and +1.7°C, respectively, making both seasons the third warmest on record. In November, some stations in southern and eastern Spain reported record-breaking monthly mean temperatures at stations with long histories (e.g., Valencia, with observations dating back 141 years.)

(ii) Precipitation

Iberia experienced, on average, near-normal conditions during 2009, with only local sectors of central and southern Iberia receiving less than 80% of the climatological average (Fig. 7.30). Dry episodes are relatively common in Iberia and, regarding the duration and intensity of dry periods in this context, 2009 can be classified as a moderately dry year, particularly when compared with exceptional dry years such as 2005. Nevertheless, all seasons recorded lower-than-average precipitation for the aggregated area of Iberia (Fig. 7.33), particularly spring, summer, and autumn, but December 2009 was an exceptionally wet month.

May was especially dry (40% of normal), with some stations in northeastern Spain recording new historical minima (as low as 1.1 mm) in a series of up to 130 years. June showed a remarkable dipole pattern over Iberia. While the eastern half of the Peninsula, particularly the Mediterranean coast, was dry, Galicia and much of Portugal were quite wet, with the impact even discernible in the summer (JJA) average (Fig. 7.33, JJA). Rainfall anomalies exceeded 150% along the Atlantic coast. Monthly mean anomalies for June in Lisbon reached nearly 300% (59 mm), although June is a relatively dry month and hence moderate values of precipitation can result in a large percentage anomaly.

Averaged across Iberia, autumn seasonal mean deficits were similar to spring and summer; though some regions, like the southern Mediterranean coast, were much wetter than normal. The year closed with considerably wetter-than-average conditions in much of Iberia during December 2009. In southeast Spain, December precipitation was more than twice normal.

(iii) Notable events

On 24 January, an exceptional storm hit northern Spain with strongest gusts reaching 190 km hr^{-1}. It was the worst storm in this region since 1999 (see sidebar).

On 27–29 September, heavy precipitation was recorded at a number of locations on the Spanish southeastern coast. Although such convective episodes are typical for that time of the year, the event of 27–29 September significantly contributed to the very high monthly totals, which broke records at some locations in southeastern Iberia (e.g., Alicante with 309 mm; records commenced in 1939) and the Balearic Islands (e.g., Palma, with 222 mm; series commenced in 1951).

EXCEPTIONAL STORM STRIKES NORTHERN IBERIA AND SOUTHERN FRANCE—R.M. TRIGO, D. BARRIOPEDRO, C.C. GOUVEIA, A. OBREGÓN, P. BISSOLLI, J.J. KENNEDY, AND D.E. PARKER

An exceptional North Atlantic storm swept through northern Iberia and southern France on 23–24 January 2009. The storm (labeled Klaus by the German Weather Services, DWD) developed off Bermuda on 20 January and crossed the Atlantic, reaching the Bay of Biscay in the early hours of the 23rd, where it deepened further (Liberato et al. manuscript submitted to *Weather*). The strongest winds induced by Klaus were felt in northern Spain, including the large populated cities of Santander, Bilbao, and Barcelona (Fig. 7.36). But it was in southern France (namely in the cities of Bordeaux, Narbonne, and Perpignan) that the wind gusts surpassed many previous records. The highest level of wind warning possible was issued by Meteo France, though sadly at least 20 fatalities occurred that were a direct consequence of the storm. More than one million homes suffered power cuts as trees and power lines were downed, while road and rail links were blocked and airports closed. Klaus was considered the most damaging wind storm to affect northern Iberia, southern France, and the western Mediterranean since the storm Martin in late December 1999, which killed 88 people and uprooted millions of trees (Liberato et al. manuscript submitted to *Weather*).

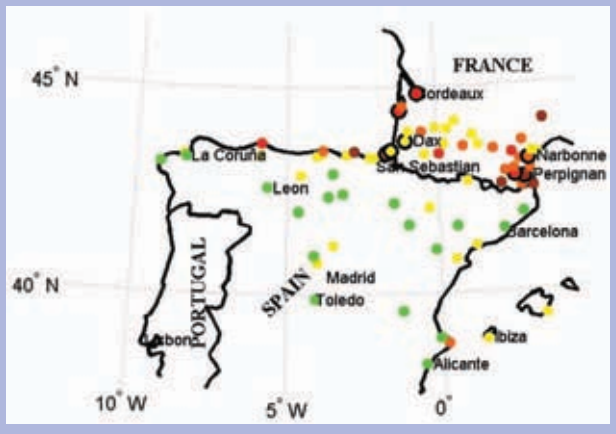


Fig. 7.36. Maximum wind gusts recorded in Spain and southern France (on either 23 or 24 January 2009). Green (100–120 km hr^{-1}), yellow (120–140 km hr^{-1}), orange (140–160 km hr^{-1}), red (160–180 km hr^{-1}), and brown (180–200 km hr^{-1}). Stations which set new wind gust records are highlighted with a solid circle around the color circle.

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

Countries considered in this section include: Italy, Malta, Slovenia, Croatia, Serbia, Montenegro, Bosnia and Herzegovina, Albania, Macedonia, Greece, Bulgaria, and Turkey.

(i) Temperature

Much of Southeastern Europe was 1°C–2°C warmer than average during 2009 (Fig. 7.29), exceeding anomalies of +2°C over eastern Slovenia and +2.5°C in northeastern Italy and western Slovenia. Throughout Croatia, very high annual temperatures prevailed, exceeding the 98th percentile of the 1961–90 distribution over most regions. In Zagreb, it tied with 2008 as the third warmest year since 1862. In Turkey, the 2009 mean temperature was 0.9°C above the 1971–2000 average.

Winter temperatures were near normal over most of the region (Fig. 7.32a). Negative anomalies were observed over the western Mediterranean, Sicily, Sardinia, and in parts of Italy. The largest positive anomalies were recorded in Bulgaria and Montenegro, where many locations in the East recorded their warmest winter on record.

Spring and summer were exceptionally warm except in Turkey, which was colder than normal (Fig. 7.32b,c). April was particularly warm in Serbia and Croatia (Fig. 7.34). May was the third warmest in the last two centuries in Italy, mainly due to a heat wave at the end of the month. Another very strong heat wave in July brought temperatures of 40°C–45°C to various places in Italy. The official peak value was 45.0°C in Decimomannu, Sardinia, a new local record. In Mostar (Bosnia and Herzegovina), it was the warmest summer on record. September was particularly warm in Turkey, with maximum and minimum temperature records broken in a number of locations.

In Italy, December was a month of strong contrasts. A cold spell between 18–23 December saw a number of records broken in northern Italy, with temperatures falling below -15°C in a number of locations. Only days later, on 25–30 December record high temperatures were recorded across central and southern Italy, with temperatures exceeding 25°C. In Bulgaria, several stations registered record high temperatures on Christmas Day (e.g., 21.2°C in Vratsa). December mean temperature was well above normal

in Turkey and also in Macedonia, which recorded monthly mean anomalies of greater than +4°C in places.

(ii) Precipitation

The year brought well-above-average precipitation over most of the southwestern Balkan Peninsula and southern Italy, exceeding 125% of normal in most places (Fig. 7.30). In Croatia, rainfall was significantly below average in the East, while on the southern Adriatic coast precipitation was above the long-term mean. Some places in Turkey recorded 150% of their annual average.

Winter brought wetter-than-normal conditions over most of Italy and the Balkan Peninsula, with the exception of Bulgaria (Fig. 7.33, DJF). January rainfall was particularly high, with maxima in Greece and on the Adriatic coast of the Balkan Peninsula. Luqa Airport on Malta received its highest monthly rainfall total in 85 years (247 mm).

The northern Balkan Peninsula experienced drier-than-normal conditions during spring, while wetter conditions occurred in the South. March precipitation in Athens was twice the normal. The eastern Balkan Peninsula had a very dry April, but places in northern Italy registered their second wettest April in 75 years or more, resulting in the flooding of the Po River.

It was generally wet during June. Monthly average totals were exceeded by more than 25% with the exception of northern Italy, southern Greece and western Turkey, which were all very dry. July and August were mostly dry.

Abundant rainfall occurred in southern Italy and Sardinia in September and October, whereas drier-than-average conditions occurred in Tuscany and northeastern Italy. Autumn was also very wet in the southern and eastern parts of the Balkan Peninsula (Fig. 7.33, SON). September brought exceptional rainfall totals to Athens (48 mm or 480% of 1961–90 average). Serbia and northern parts of Bulgaria were very wet during October.

December was also generally wetter than average across the region. Several stations in northern Italy recorded their wettest or second wettest December in nearly 90 years, mainly due to an intense precipitation event around Christmas. An exceptional local 24-hr precipitation record was set in Makrinitsa in central Greece, where 417.2 mm fell on 10 December. This corresponds to nearly half of the total rainfall for 2009 at this station. Other locations also received exceptional precipitation on that day, resulting in significant flooding and widespread damage.

(iii) Notable events

An outbreak of cold air from Eastern Europe brought abundant snowfall over northern Italy from 3–10 January. Temperatures dropped below 0°C in many places. On 7 January, a snow depth of 26 cm was reported in Milan.

On 24 February, exceptionally heavy rainfall in Malta led to the cancellation of the National Carnival grand finale. A heavy storm over the western Mediterranean with gusts up to hurricane force, heavy rain, snowfall, and high seas followed on 4–6 March due to a cut-off cyclone.

From 20–22 June, an Atlantic disturbance affected most of Italy with heavy rainfall and strong winds. Daily precipitation on 21 June set new records at four locations which had 58 years of record.

On 7–12 September, torrential rains and flooding affected northwestern Turkey, with the heaviest rainfall in 80 years. Istanbul received 67 mm of rain within one hour on 9 September.

A violent storm crossed southern Italy on 15–17 September, flooding the city of Palermo (Sicily). On 2 October, a storm dropped 70 mm of rain within six hours in Messina, Sicily. Civil protection measurement stations recorded up to 300 mm of precipitation at mountainous sites, resulting in Italy's worst mudslides in more than a decade.

Abundant snowfalls occurred from 18–20 December over northern parts of Italy, with depths up to 30 cm. Subsequent warming and continuous rainfall resulted in rapid snowmelt causing extensive flooding in Tuscany just before Christmas.

6) Eastern Europe—A. Obregón, P. Bissolli, J. J. Kennedy, and D. E. Parker

Countries considered in this chapter include: European Russia, Belarus, Ukraine, Moldova, and Romania.

(i) Temperature

Annual temperature anomalies over Eastern Europe ranged between +1°C and +2°C (Fig. 29), with only northern parts of European Russia recording anomalies below +1°C. Parts of Romania exceeded anomalies of +2°C. Moldova experienced its second warmest year in history, beaten only by 2007.

Unlike most of Western Europe, Eastern European countries experienced well-above-average temperatures during winter 2008/09 with anomalies surpassing +2°C (Fig. 7.32a).

Spring temperature anomalies exceeded +1°C in western parts of Belarus, Ukraine, and Romania (Fig.

7.32b). April was particularly mild, although there was a 10 to 20 day frost period in the Ukraine, notably in eastern parts of the country. April was colder than normal in European Russia (Fig. 7.34).

Temperature anomalies reached +3°C in the Ukraine during June and July, with a highest daily maximum temperature for the region of 40°C. Summer temperature anomalies exceeded +1°C in Romania and Moldova, while anomalies in European Russia (+0.5°C) and Belarus were closer to normal.

Autumn was characterized by the extremely mild months of September and November throughout Eastern Europe, with temperatures generally above the 90th percentile of the 1961–90 distribution. These months contributed to a seasonal anomaly of over +1°C in Romania, Moldova, Belarus, western parts of Ukraine, and northern parts of European Russia, while the eastern Ukraine and southern European Russia had anomalies in excess of +2°C (Fig. 7.32d).

December temperatures in Belarus differed greatly during the month. The beginning of the month was anomalously warm, with temperatures ranging from 5°C–10°C above average. On 2 December, several locations set new records for this day including Minsk, where temperatures reached 9.3°C, and Moscow (8.1°C), while in Moldova, it was the warmest night for a 2 December in the past 65 years. However the warmest day in Moscow in December 2009 was on the 6th, with 9.4°C. Remarkably, this value was measured in the early morning and was a local record high for December. In sharp contrast, temperatures plunged below -15°C in the middle of December in many parts of Belarus, with temperatures falling as low as -27°C. The city of Perm in European Russia (in the lowlands near the Ural Mountains) experienced temperatures as low as -41.4°C on 16 December, which was a new local record.

(ii) Precipitation

Precipitation totals in 2009 were generally close to or above average for most of Eastern Europe (Fig. 7.30). Only a few places in the Ukraine and central European Russia reported a rainfall deficit, recording 60%–80% of average. Annual precipitation in the north of European Russia exceeded 125% locally.

Winter 2008/09 brought near-normal precipitation (Fig. 7.33, DJF) to the region; only a few scattered locations in Eastern Europe received considerably above-average seasonal totals. It was dry, however, in eastern parts of European Russia, with some areas receiving less than 40% of their normal precipitation.

Spring was dry in Moldova, with areas receiving only 50%–75% of their average rainfall for the season. Similarly, parts of Romania and Ukraine were also dry. April was particularly dry in the western regions. In Moldova, only 11.5 mm (26% of normal) of rainfall was recorded, making April the second driest in 60 years, second only to April 1974 (9mm). April was also drier than average in the Ukraine and Russia, where many stations reported monthly rainfall amounts below the 10th percentile.

Summer was unusually wet in Belarus (second wettest since 1936), mainly due to well-above-average precipitation during June and July. Minsk reported a new record of monthly precipitation in June (187 mm, more than twice normal). However, August had only about half of the normal precipitation totals in Belarus.

Autumn precipitation was well above average over northern European Russia and Belarus, as well as in western parts of Romania and Ukraine (Fig. 7.33, SON), with October being particularly wet. Belarus received more than twice its normal rainfall and in Romania precipitation exceeded 150% of normal in most places, with some areas exceeding 200%. In contrast, autumn was dry in Moldova and in central parts of Ukraine.

There was a heavy snowfall in Moscow at the end of December, when 19 cm fell within 24 hours. A new record daily snowfall of 31 cm was set in Kyiv, beating the previous record by 3 cm. Ukraine saw heavy snow storms in the first half of December.

7) Middle East—A. Obregón, P. Bissolli, J. J. Kennedy, and D. E. Parker

Countries considered in this section include: Israel, Cyprus, Jordan, Lebanon, Syria, western Kazakhstan, Armenia, Georgia, and Azerbaijan.

(i) Temperature

Warmer-than-average conditions prevailed throughout the region during 2009. The largest anomalies were experienced in Israel, Cyprus, and the western parts of Syria and Kazakhstan, with values generally ranging between +1°C and +2°C (Fig. 7.29).

The largest positive temperature anomalies in winter 2008/09 were in the Caucasian countries (i.e., Armenia, Georgia, Azerbaijan) and Israel. On 9 February, temperatures above 30°C were recorded in parts of Israel, while between 13–16 February temperatures reached 20°C in southern Armenia. While spring and summer temperatures were well above average in Jordan, Syria, Israel, and Cyprus,

temperatures in western Kazakhstan, Armenia, Georgia, and Azerbaijan were cooler than average. June 2008 and 2009 were the two warmest Junes in the last 40–50 years in Israel, due to several Sharav (hot winds from the Arabian Desert) events. Autumn temperature anomalies exceeded +1°C in Georgia and Azerbaijan and up to +2°C in western Kazakhstan. Israel experienced a very hot October with a monthly mean anomaly exceeding +3°C (1981–2000 base), primarily due to a six-day heat wave between 15–20 October, with successive days above 35°C in many places. December was unusually warm over the whole Middle East (+2°C anomaly or more), most notably during the second half of the month.

(ii) Precipitation

Southern parts of Israel, Jordan, and parts of Syria received less than 80% of their annual rainfall average (Fig. 7.30). Anomalies below 40% of normal were restricted to southern and eastern parts of Jordan. For the sixth year in succession, Israel's 2008/09 rainfall season delivered below-average rainfalls, with resulting water shortages and deteriorating quality of ground water reservoirs. In contrast, Georgia and Armenia recorded 100%–125% of normal, while annual precipitation in western Syria, Lebanon, and Cyprus was in the range of normal to slightly below normal, bringing to an end a three-year drought period in Cyprus.

In western Kazakhstan, the first half of the year featured a contrasting temporal pattern of rainfall. Winter was particularly dry with areas receiving less than 40% of average precipitation, while spring rainfall was significantly above average, exceeding 160% of normal in places. In the rest of the region, winter and spring precipitation were generally below average (Fig. 7.33, DJF, MAM). Israel had very little rainfall in January, less than 20% of the monthly long-term average, making it one of the driest in the 70-year measurement history; yet, February was the third rainiest in 70 years. Summer was unusually wet in Armenia. Rainfall, sometimes heavy, was reported almost every day during July–September. Autumn was generally very wet across the Middle East (Fig. 7.33, SON), particularly in the Caucasian countries and Syria. In September, the monthly rainfall in Cyprus was eight times higher than normal. Israel also had very heavy rainfall during September and October, marking an early start to the 2009/10 rainy season. In December, Cyprus once again experienced heavy precipitation, with a hailstorm on the 16th resulting in a monthly total of almost 150% of the normal.

(iii) Notable events

Severe rainfall was recorded in northern Israel on 27–28 February. Precipitation amounts of 100 mm–180 mm over 48 hours caused flooding and extensive damage to agriculture. This event also affected Cyprus, with flooding in a number of places.

Severe drought conditions, which began in 2006, affected eastern Syria during August. Thousands of Syrian farming families were forced to migrate to cities after two years of drought and failed crops. However, high September rainfall brought an end to this drought period.

Accompanied by heavy precipitation and hailstorms, a tornado affected several areas in Cyprus on 18 September causing injuries and significant damage. Tornadoes of lower intensity along with large hail on 19 September affected areas around Nicosia.

g. Asia

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

(i) Temperature

The year 2009 was warm in Russia, with the mean annual air temperature, averaged over the Russian territory, 0.6°C above the 1961–90 average (Fig 7.37). This anomaly was substantially smaller than those recorded in the two previous years, when anomalies were close to +2°C.

During January, a large warm region formed in northeastern Siberia, with mean monthly air temperature anomalies exceeding +10°C in the southeastern Siberian Taimyr Peninsula. As a result, frequent snowfalls, with winds as strong as 108 km hr^{-1} and poor visibility (down to as little as 50 meters) occurred in the southern areas of the peninsula. It was also very warm in northern Western Siberia, as well as in northwestern European Russia. Simultaneously, in the first 10 days of the month, severe frosts (-35°C

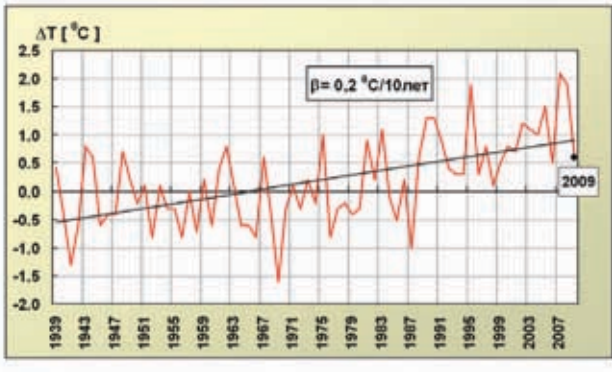


Fig. 7.37. Anomalies of annual mean air temperature averaged over the Russian territory for the period 1939–2009 (base period: 1961–90).

to -44°C) persisted in southern Western Siberia and in the Irkutsk Region, with lowest minima of -49°C and observed frost fogs. Extreme cold weather was also recorded in the far eastern regions of Chukotka, the Magadan Region, and northern Kamchatka, with temperatures as low as -50°C. As a result, the mean monthly air temperature in these regions was 8°C–10°C below normal.

February was warm over most of European Russia but cold over Asian Russia. In European Russia, the warmest weather was observed in the northwestern and southern areas, where mean monthly air temperatures were 4°C–5°C above normal. As for the Asian territories, the first and second 10-day periods were the coldest, with mean daily air temperatures in the Tomsk Region 10°C–20°C below normal. In early February, severe frosts persisted in Taimyr and Evenkia, with temperatures as low as -50°C to -58°C.

During March, record-breaking low air temperatures were recorded in the Krasnoyarsk Territory, Transbaikalia, western Yakutia, and the Amur Region. Over much of the rest of the country it was very warm. Throughout March, record-breaking maximum daily temperatures were registered at meteorological stations in the Krasnodar Territory, Bashkiria, southern Ural, the Central Volga Region, southern Western Siberia, Kolyma, and the northern Khabarovsk Territory.

April was cold over European Russia, while in contrast the whole of Asian Russia recorded positive temperature anomalies (Fig. 7.38). In the latter half of the month, record-breaking cold weather spread into central Russia and southern areas of European Russia. New record daily minima were set in Tambov, Kursk, Lipetsk, Krasnodar, Mineralnye Vody, Sochi, and Makhachkala. At some meteorological stations, extreme low daily air temperatures (below the fifth percentile of all the April minimum temperatures from 1961 to 1990) persisted for more than 10 days (Fig. 7.38b). In Eastern Siberia, anomalies of mean monthly air temperature exceeded 6°C in Evenkia and southern Taimyr. In the first and third 10-day periods of the month, new record maximum temperatures were set at stations in the region (see the inset in Fig. 7.38). Extremely high temperatures (above the 95th percentile of all April maximum temperatures from 1961 to 1990) were observed for more than 10 days (Fig. 7.38a). Over the Far East territories, mean

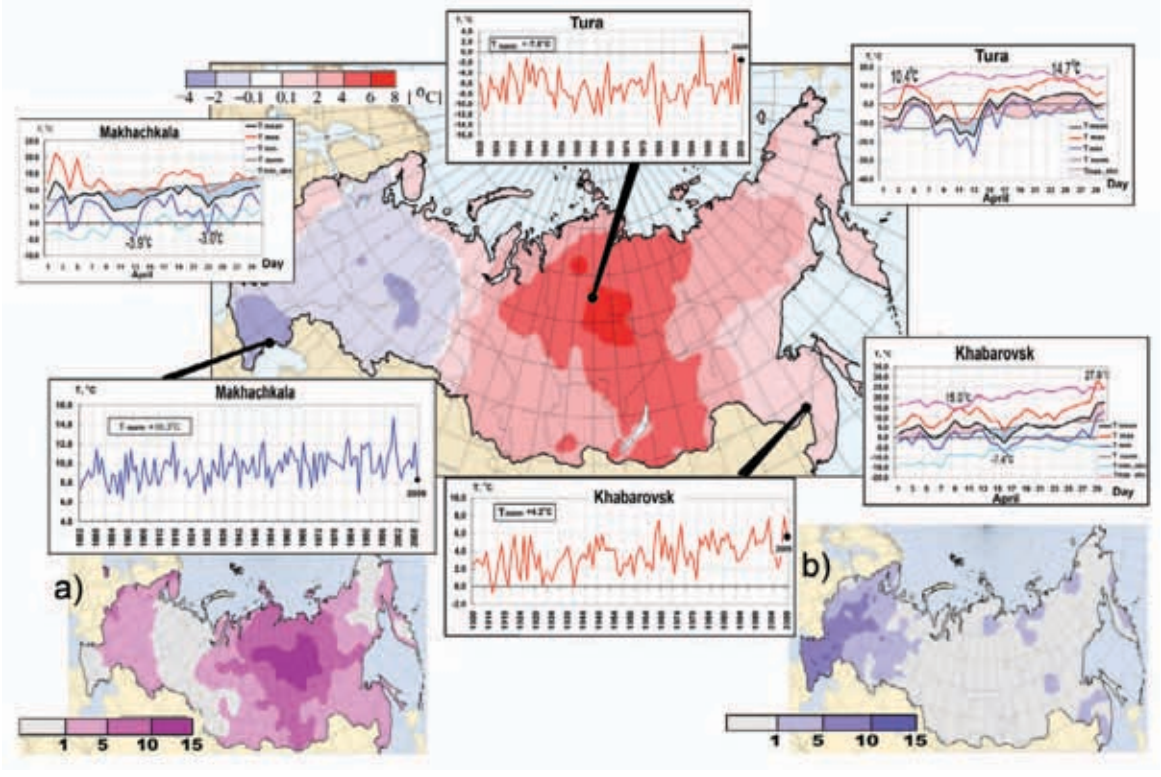


Fig. 7.38. Air temperature anomalies in April 2009. Insets show mean April air temperatures and mean daily air temperatures in April 2009 at meteorological stations Khabarovsk, Makhachkala and Tura; (a) Number of days with high temperature extremes in April 2009; (b) Number of days with low temperature extremes in April 2009.

monthly temperature anomalies exceeded +5°C in northwestern Yakutia. In the southern Far East, heat waves and cold snaps alternated several times throughout the month, with both record monthly maxima and minima temperatures being set. In early April, record-breaking maximum daily air temperatures occurred in the Khabarovsk Territory, Maritime Territory, and Amur Region. Another record-breaking heat wave came to the southern Khabarovsk Territory and the Maritime Territory late in April. In the Khabarovsk Territory, extremely low air temperatures were recorded in between these heat waves in mid-April. In some areas of the Territory, record values of minimum daily temperatures were broken.

In some contrast, May saw mean monthly air temperatures close to normal over most of the Russian territory. The largest positive anomalies (up to +6°C) were found in the northern Far East (Kolyma and Chukotka). In the Maritime Territory, temperatures were, at times, as warm as they were during summer (30°C–34°C). Maximum temperature records were exceeded in Vladivostok, Blagoveshchensk, and Yuzhno-Sakhalinsk.

June was very warm in southern European Russia. On 25 June, new temperature records were set in five cities of the region. Above-normal temperatures were also recorded in Yakutia and the northern Far East. In Oimyakon, the mean monthly temperature anomaly exceeded +6°C. New record-breaking maximum daily temperatures were recorded in Yakutia, Chukotka, and the Magadan Region. In Kamchatka, as early as the beginning of June, air temperatures exceeded 20°C. Such warm temperatures so early had never been noted in the history of meteorological observations in this region. In July, temperatures were close to normal over Russia as a whole; however, arctic air penetrated into Western Siberia and eastern European Russia, contributing to extremely low temperatures. In contrast, southern European Russia was hot in July, with air temperatures reaching record levels (40°C–42°C) in the Volgograd and Astrakhan regions.

Although August temperatures were largely close to normal, cold weather dominated central and southern European Russia, with some southern areas experiencing their coldest August in more than 30 years. New daily air temperature minima were registered in many cities of the region (e.g., Kotlas, Pskov, Saratov, Volgograd, Krasnodar, Stavropol, Mineralnye Vody). In contrast, September, under the influence of the Azores anticyclone, proved to be abnormally warm in European Russia, the Ural region, and Western Siberia. New record temperature maxima were set in the same cities.

October was very warm and largely dry in southern and eastern European Russia, Ural, Western Siberia, and northern Eastern Siberia. In Eastern Siberia, maximum positive mean monthly air temperature anomalies of more than +10°C were recorded on the Arctic islands.

November was warm in European Russia, with mean monthly air temperatures being 2°C–3°C above normal. In the north of Eastern Siberia (Taimyr and the Arctic islands), mean monthly air temperatures were 4°C–10°C above normal, although on the last days of November, Taimyr experienced severe frosts (-35°C to -40°C). In contrast, December air temperatures were below normal over much of the Russian territory (Fig. 7.39). Very cold weather was observed in northern and northeastern European Russia and in Ural, with mean daily air temperatures being up to 30°C below normal. Arctic air penetrated into the Upper Volga and Central Volga areas. In the city of Kazan, minimum temperatures were the lowest since records began in 1872. On 16 and 17 December, record minimum temperatures were recorded in the city of Perm, with -41.4°C and -38.4°C, respectively. The center of the cold area was over Western Siberia, where mean monthly air temperature anomalies reached -9°C to -11°C.

(ii) Rainfall

Precipitation over Russia was generally near normal (80%–120%) for the year. Above-normal precipitation (120%–140%) was recorded in the northwestern areas of European Russia and in areas of southern Siberia and the Far East.

During January, the areas of extreme cold in far eastern Russia also experienced large precipitation deficits, recording only 2%–20% of their monthly average. In contrast, across the southern Far East, active cyclogenesis caused heavy snowfalls. At meteorological station Ternei, the snowfall recorded over only two days was the equivalent of 185 mm of precipitation, approximately 1200% of the January average.

In March, precipitation in the Okhotsk area was up to 600% of normal, breaking March records at a number of stations. Transportation between the city of Okhotsk and other cities of the Khabarovsk Territory was brought to a standstill for a week, and snow buried some houses. In contrast, during April, Transbaikalia recorded above-average temperatures and a significant precipitation deficit (6%–30% of normal), resulting in greatly increased fire risk.

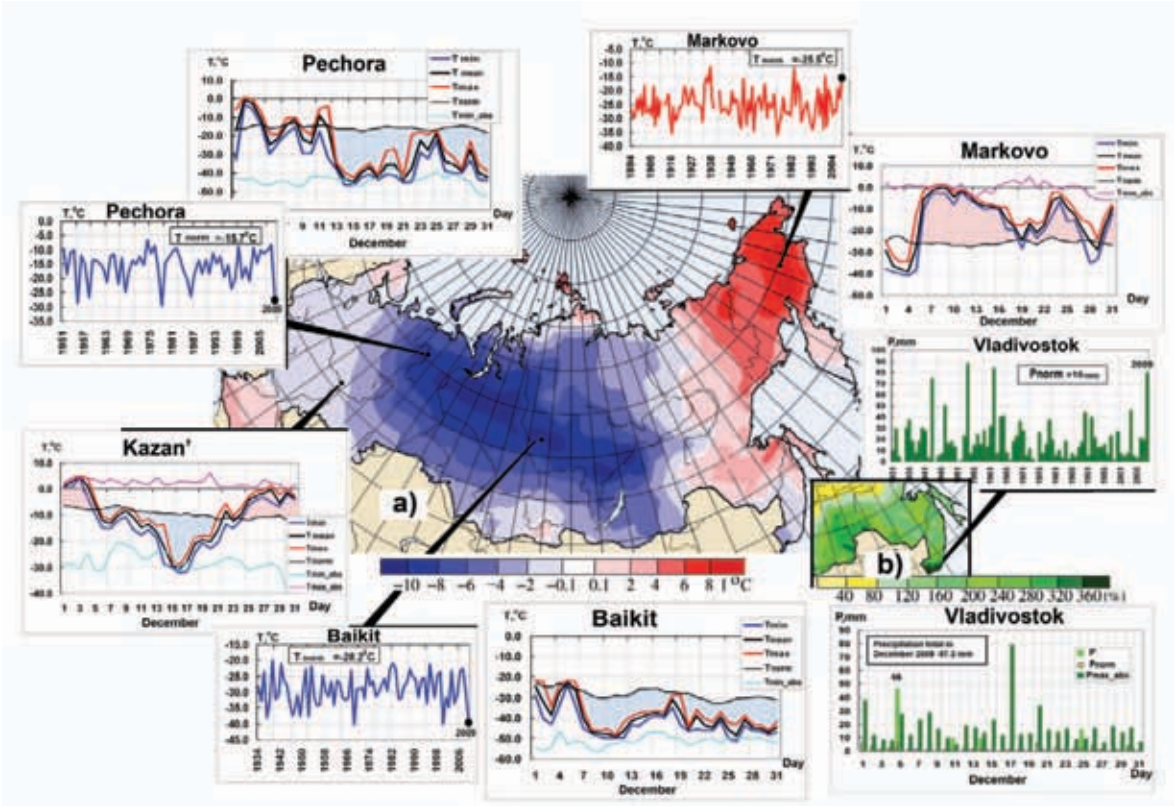


Fig. 7.39. Weather conditions in December 2009. (a) Air temperature anomalies. Insets show the series of mean monthly and mean daily air temperatures in December 2009 at meteorological stations Pechora, Baikit, Markovo, and Kazan. (b) Percentage of monthly mean precipitation in the southern Far East. Insets show the series of monthly and daily precipitation totals in December 2009 at meteorological station Vladivostok.

June saw large precipitation anomalies in southern Eastern Siberia and the southern Far East. In Sakhalin and the Maritime Territory where peak rainfall occurs in the latter half of summer with the monsoon, rainfall peaked in early June, with southern Sakhalin and the Ternei area of the Maritime Territory flooded due to frequent rains. Monthly precipitation was two to three times the average, with most of the rainfall occurring in just a few days, resulting in flooding. Such high early season rainfalls have never been observed before.

Autumn was particularly wet over parts of eastern Russia. In Northern Caucasia, September was very rainy in the Krasnodar and Stavropol Territories and the Chechen Republic. Particularly heavy rains were recorded in Dagestan on 20–21 September, causing mud flows, river floods, and significant economic damage. October was also very rainy on the coast of the Sea of Okhotsk. Ayan, for example, received more than five times its monthly average rainfall. Typhoon Melor brought heavy rainfall and hurricane-strength winds (up to 144 km hr^{-1}) to the Southern Kuril Islands. During November, precipitation was significantly above normal in Dagestan for the second month running. Makhachkala, for example, received more than 500% of its normal November rainfall, with avalanches in mountain regions.

In December, the Kemerovo Region and the Republic of Altai received more than double their monthly normal rainfall. In Chukotka, very warm conditions (anomalies between +9°C and +10°C) were accompanied by rainfall that was twice the long-term average. Even more precipitation fell in the southern Khabarovsk Territory and the Maritime Territory, where some meteorological stations recorded 400%–600% of their monthly mean. Vladivostok received 87.3 mm for the month against an average of only 18 mm, with more than half the precipitation (46 mm) falling on 5 December (Fig. 7.39b).

(iii) Notable events

In early January, ice slush buildup occurred at Sochi (Black Sea coast), with a maximum depth of 96 mm, while 38 avalanches, with volumes as large

as 30 m^3 to 200 m^3, occurred in Northern Caucasia on 7 January. An additional 52 avalanches occurred in the same region on 24–25 March.

During May, the Krasnodar Territory received 107 mm of rainfall in six hours on the 11th, while on 29 May the Astrakhan Region received 141 mm of precipitation in five hours.

On 4 June, large hail (50 mm–70 mm in diameter) fell in southern European Russia (Krasnodar Territory), while numerous mud flows caused by heavy rains occurred in Dagestan (Northern Caucasia) on 18–19 June. In contrast, July brought 142 forest fires over an area of more than 105 000 ha in the Magadan Region. August again brought heavy rain and floods to the rivers Detrin, Ola, Arman, and Kolyma (30–31 August, Magadan Region), while heavy rainfall in the Upper Volga region (Republic of Mordovia) on 8 August saw 80 mm fall in only 48 minutes. Heavy rainfall also fell on 21 September in Makhachkala (Republic of Dagestan), when they received 100.2 mm of precipitation in just three hours.

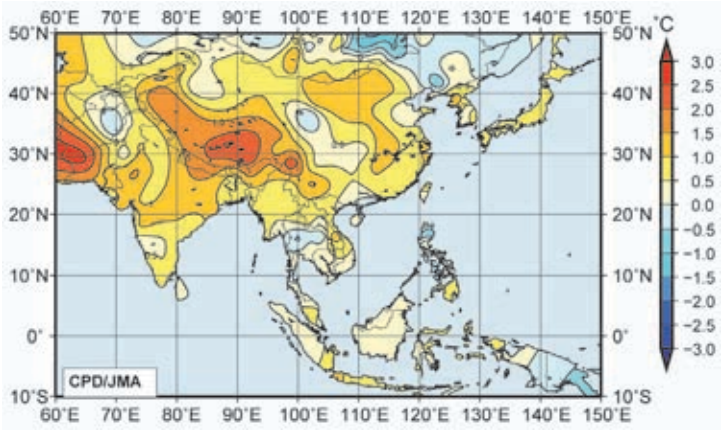


Fig. 7.40. Annual mean temperature anomalies (°C; 1971–2000 base period) over East Asia in 2009. (Source: Japan Meteorological Agency.)

2) East Asia—K. Osawa, P. Zhang, Y. Zhu, and H. Na

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

In the first half of 2009, anticyclonic anomalies in the upper troposphere were dominant over China, a pattern which is consistent with the La Niña event early in the year. During the boreal summer, the subtropical jet stream became stationary, with a ridge over China and a trough over the Korean Peninsula, significantly affecting conditions over the region. Likewise, a trough became dominant over Mongolia and China during November and December.

Over most of East Asia, the annual mean surface air temperature during 2009 was near or above normal, with the notable exception of northeastern China (Fig.7.40). Temperatures for most of East Asia were significantly above normal during February, May, and June, while significantly-below-normal temperatures were observed over eastern China and Mongolia during November and December.

Annual precipitation totals were above normal on the Pacific side of northern Japan, eastern to central China, and Hai Nan Island. In contrast, precipitation was below normal on the Pacific side of western Japan, in Okinawa/Amami, over southern and western China, and around Mongolia (Fig. 7.41). In August, Typhoon Morakot caused significant damage to parts of the Taiwan province of China, resulting in over 600 fatalities.

(i) Temperature

The mean temperature over China for 2009 was 9.8°C, 1.0°C above the 1971–2000 normal, the fourth warmest year since records began in 1951 and the 13th above average year since 1997. Annual mean temperatures for 2009 were above normal over most of China, with temperatures 1°C–2°C above normal in west and central east China. In contrast, some parts of the northeast and southern areas of South China recorded below-average temperatures for the year. Temperatures over China were above normal (based

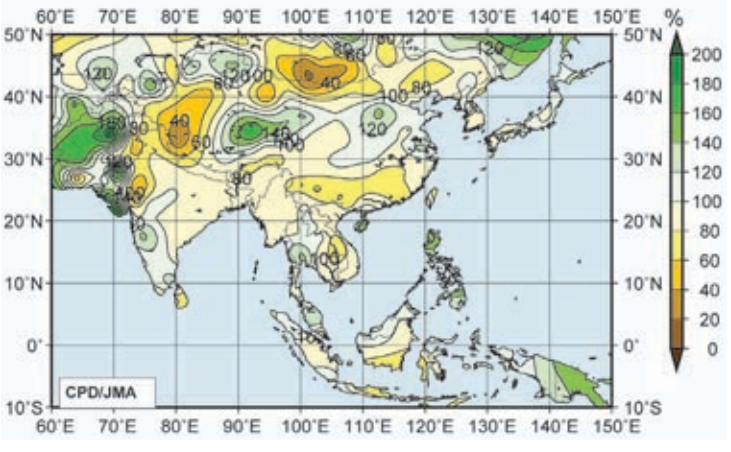


Fig. 7.41. Annual precipitation ratio as percentage of normal (1971–2000 base period) over East Asia in 2009. (Source: Japan Meteorological Agency.)

on the 1971–2000 climatology) for all seasons, with anomalies of 1.7°C, 1.3°C, 0.6°C, and 0.6°C for winter, spring, summer, and autumn, respectively. The winter 2008/09 mean temperature was the third warmest, and the spring value second warmest, since 1951.

The average surface temperature over Japan (averaged over 17 observatories confirmed as being relatively unaffected by urbanization) in 2009 was 0.56°C above the 1971–2000 average, making 2009 the seventh warmest year since 1898. Area-averaged annual mean temperature anomalies were +0.6°C in northern Japan, +0.7°C in eastern Japan, +0.6°C in western Japan, and +0.5°C in Okinawa/Amami.

(ii) Precipitation

The average annual precipitation over China was 574.0 mm, 38.8 mm below normal, making 2009 the fourth driest year since 1951 and the driest year since 1987. While spring precipitation was near normal, the seasonal totals for winter, summer, and autumn were all below average. Autumn precipitation was the driest in the last 10 years. As a result of the dry year, China suffered severe drought during 2009. In late 2008 and early 2009, serious autumn and winter rainfall deficiencies affected the northern wheat growing areas. From April to May, severe spring drought impacted Heilongjiang and northeastern Inner Mongolia. From late June to early November, severe summer and autumn drought occurred in Liaoning, Jilin, and southeastern Inner Mongolia. Similarly, from August to early November, severe autumn drought impacted Hunan, Jiangxi, Guizhou, Yunnan, Guangxi, and Guangdong, resulting in water levels in parts of the Gan and Xiangjiang rivers being the lowest recorded in the past 50 years. During the summer, the precipitation in eastern China was near to below normal, while precipitation was about 30% below normal in the southern part of Northeast China and the middle part of Inner Mongolia.

In Japan, annual precipitation was significantly above normal on the Pacific side of northern Japan. Conversely, rainfall was below normal on the Pacific side of western Japan and Okinawa/Amami, but near normal in other areas. Several tropical cyclones, and the lingering Bai-u front along the Japanese archipelago (consistent with the weak northward expansion of the North Pacific High), brought unusually wet and cloudy conditions to western and northern Japan during July 2009. A new record for monthly total precipitation for July was set on the Pacific side of northern Japan (209% of the 1971–2000 normal), and correspondingly, the Sea of Japan side of the country experienced its lowest monthly sunshine duration since 1946. Some crop damage and a rise in vegetable prices were reported in association with this unsettled weather. The active Bai-u front also caused disastrous flooding in western Japan in July 2009.

(iii) Notable events

Over the western North Pacific and the South China Sea, 22 named tropical cyclones (TCs) formed in 2009, 13 of which reached typhoon intensity. This total is less than the 30-year (1971–2000) average frequency of 26.7. Although the formation of the first named TC in 2009 was relatively late, the total number of cyclones (21) that formed from May to October was similar to the 30-year average frequency of 21.3. Morakot swept across the Taiwan Province and caused more than 400 deaths and severe damage to agriculture and infrastructure.

In spring 2009, China was affected by seven dust and sand events (five dust storms, two blowing sand), which was significantly less than 2000–08 average of 13.3 events. The average number of dust days across all recording stations in northern China was 0.9 days (4.7 days less than normal of 1971–2000), ranking the least since 1954.

The Republic of Korea was affected by a total of 10 dust events during 2009, with the strongest occurring on 25 December and lasting for two days. The average number of dust days over the 28 recording stations was 7.7 days in 2009, which was twice the normal (3.8 days) but slightly less than the most recent 10 years, which averaged 9.2 days. The number of dust days in spring 2009 was 2.5 days, which was slightly below normal (3.6 days) and one-third of the recent 10-year average (7.5 days). The year was notable in that 60% of all dust events appeared during the autumn and winter seasons.

In Japan, the number of days on which any meteorological station in Japan observed a Kosa (yellow sand/aeolian dust event) in 2009 was 22, which was near normal (20.2 days). The annual cumulative number of Kosa observations in 2009 was 251, which was above normal (163.0 days). Kosa was observed in October and December for the first time in last 17 years and 16 years, respectively.

Asian summer monsoon activity was generally suppressed throughout the season, except in the western North Pacific monsoon region. At the north periphery of the upper Tibetan High, the subtropical jet stream was stronger than normal.

The South China Sea (SCS) summer monsoon (SCSM) broke out in the 6th pentad of May and with-

drew in the 3rd pentad of October. The intensity index of the SCSM was -0.35, near normal. From the 6th pentad of May to the 2nd pentad of August, the SCSM was stronger than normal, while after mid-August it became weaker than normal (Fig. 7.42). At the end of September, the warm and wet air swiftly retreated south of 25°N, and hence by the third pentad of October the summer monsoon had withdrawn from the SCS.

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

Countries considered in this section include: Bangladesh, India, Pakistan, and Sri Lanka.

(i) Temperatures

During 2009, South Asia experienced notably warmer-than-normal conditions. January and February were characterized by unusually high temperatures. Prolonged breaks during the summer monsoon season also resulted in above-average temperatures, with many stations reporting their highest temperatures on record. Similarly, during the winter season, many parts of India and Pakistan experienced mean temperatures 3°C–5°C above their 1961–90 normal.

The annual mean temperature for India was +0.91°C above average, making 2009 the warmest year since nationwide records commenced in 1901 (Fig 7.43). This superceded the previous five warmest years on record, notably 2002 (+0.71°C), 2006 (+0.60°C), 2003 (+0.56°C), 2007 (+0.55°C), and 2004 (+0.51°C). January (+1.43°C) and August (+1.00°C) mean monthly anomalies were also the highest since 1901, while the anomalies for February, September, and December were all second highest since records began. The recent decade (2001–09) was the warmest decade on record over India with decadal mean temperature of 0.59°C.

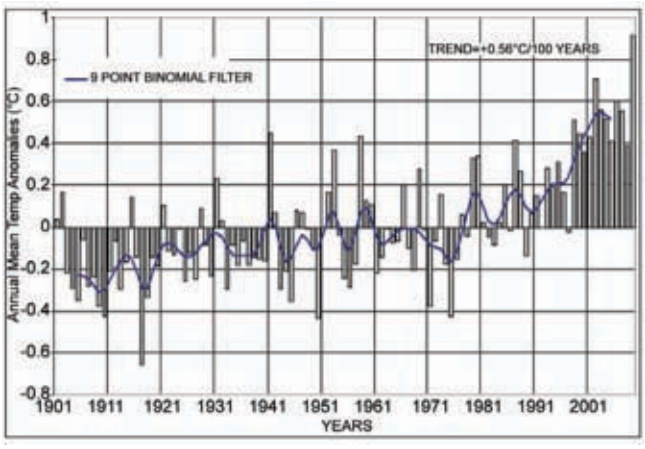


Fig 7.43. Annual mean temperature anomalies (with respect to 1961–90 normal) averaged over India for the period 1901–2009. The smoothed time series (9-point binomial filter) is shown as a continuous line.

(ii) Precipitation

The summer monsoon season (June–September) contributes 60%–90% of the annual rainfall over major portions of South Asia. In 2009, South Asia experienced one of its worst droughts since records began in 1875.

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 2009, the summer monsoon seasonal rainfall over India was only 78% of its LTA value, marking 2009 as the driest monsoon season since 1972 (76% of LTA). During the season, most parts of the country experienced large rainfall deficiencies (Fig. 7.44). The onset phase of monsoon 2009 was characterized by an early onset (23 May) over the southern parts of India. However, the formation and northward movement of tropical cyclone Aila over the Bay of Bengal and the persistent intrusion of dry air into the South Asian region due to eastward moving mid-latitude troughs disrupted the northward progress of the monsoon. The slow progress of the monsoon resulted in a record rainfall deficiency (47% below normal) for June over the country. Rainfall activity during July was near normal with monthly rainfall of 96% of the LTA. However, rainfall activity was again suppressed both in August (73% of LTA) and September (80% of LTA), making the 2009 summer monsoon season the second most deficient season since records began in 1875.

During the season, of the 36 meteorological subdivisions, only three received

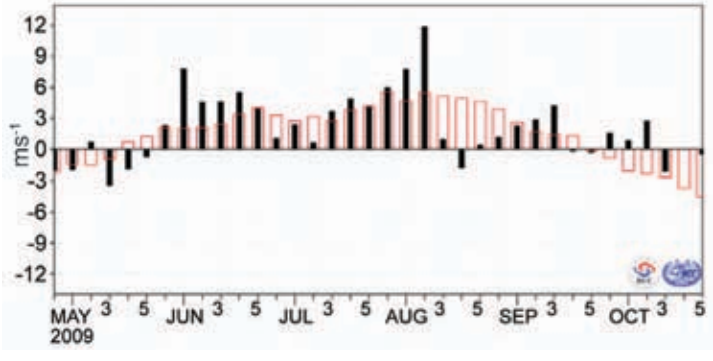


Fig 7.42. Variation of pentad zonal wind index over the monitoring region (10°N–20°N, 110°E–120°E). Red open bars are climatology (Unit: m s^{-1}) (Source: China Meteorological Administration.)

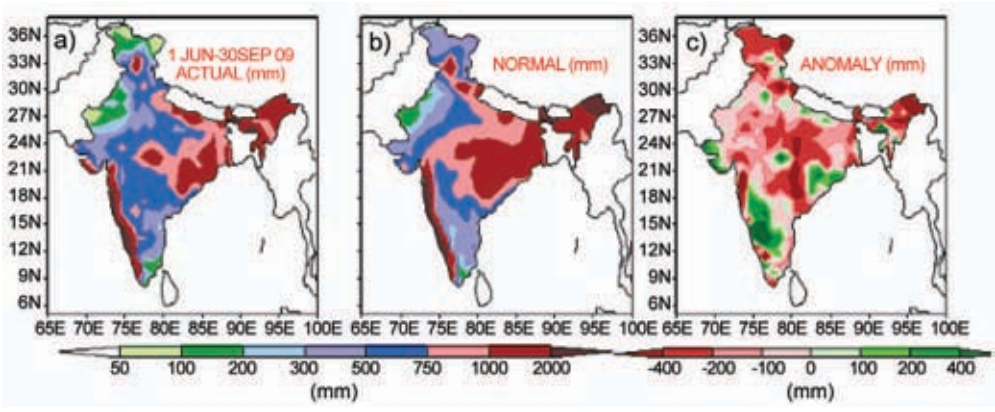


Fig. 7.44. Monsoonal (Jun–Sep) rainfall over India in 2009. (a) actual, (b) normal (base period) and, (c) anomalies (with respect to base period.)

excess rainfall, while 11 subdivisions received normal rainfall and the remaining 22 subdivisions received deficient rainfall. Out of 516 meteorological districts for which rainfall data were available, 59% of districts received 80% or less of their LTA. The 2009 summer monsoon was also characterized by strong intraseasonal variability (Fig. 7.45). Consistent with the observed decreasing trend in the frequency of monsoon depressions over the Indian Ocean, only four short-lived depressions formed during the season, against the long-term average of seven.

Over India, rainfall activity during the winter and pre-monsoon seasons was also below average. In 2009, the annual rainfall over the country was the most deficient (20% below normal) since records began in 1875, surpassing the previous record set in 1972. During the winter, rainfall over the country was 46% below normal, while during the pre-monsoon season (March–May), rainfall deficiency was 32%. While no drought had occurred over South Asia in the previous decade (1991–2000), the recent decade (2001–09) witnessed three major droughts in 2002, 2004, and 2009.

During the 2009 summer monsoon season, Pakistan also experienced one of its worst droughts. The area-weighted summer monsoon rainfall over Pakistan was 26% below its LTA. Most parts of the country, with the exception of Karachi and Hyderabad (southwest Sindh), experienced large rainfall deficiencies during the season. As a result, the 2009 monsoon season rainfall was the third lowest in the most recent decade (2001–09), after 2002 (54% deficiency) and 2004 (38%). Rainfall in July, August, and September was 9%, 41%, and 37% below normal, respectively.

The observed drought over the region had several possible causes. These include the El Niño-Modoki (warming over the Central Pacific; Ratnam et. al 2010), unusually warm equatorial Indian Ocean sea surface temperatures (Francis and Gadgil 2010), and the formation of an anomalous blocking high over west Asia with the associated descent of dry air into the Indian region (Krishnamurti et al. 2010).

The northeast monsoon (NEM) sets in over southern peninsular India during October and over Sri Lanka in late November. The NEM contributes 30% to 50% of the annual rainfall over southern peninsular India and Sri Lanka as a whole. The 2009 NEM seasonal rainfall over south peninsular India was above normal (110% of LTA), consistent with the observed relationship with El Niño. During the first week of November, heavy rainfall caused significant flooding and landslides in the southern Indian state of Tamil Nadu, sadly leading to the deaths of about 75 people. Above-normal rainfall was also reported over Sri Lanka during the season.

(iii) Notable events

Heat wave/hot day conditions prevailed over parts of central and peninsular India during the first three weeks of March; over the northern parts of the country on many days during April; and over northern, central, and peninsular parts of the country during the second half of May. There were approximately 150

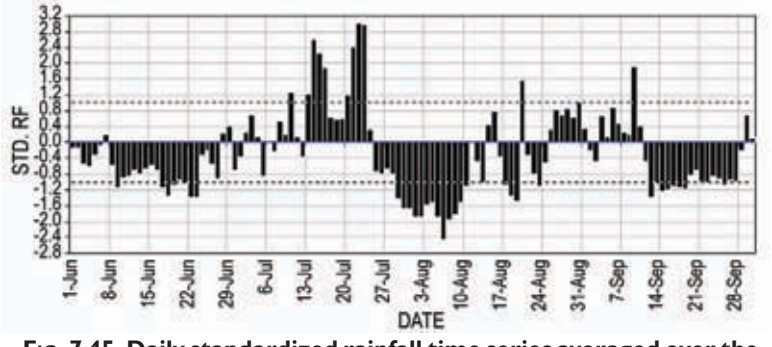


Fig. 7.45. Daily standardized rainfall time series averaged over the monsoon region of India (1 June to 30 September 2009).

Table 7.1. Record 24-hr rainfall (mm) in South Asia during 2009.

S.No.	Station	New Record	Date	Previous Record	Date	Year	Data Period
Month: June 2009							
1	Bangalore	89.6	11	76	9	1996	1901-2009
Month: July 2009							
2	Porbandar	444.3	16	252.6	16	1969	1961-2009
3	Veraval	503.8	16	361.7	23	1996	1901-2009
4	Naliya	301.3	25	273.9	21	1992	1958-2009
5	Dahanu	439.1	16	431.0	1	1956	1951-2009
6	Raipur	275.2	14	228.7	2	1970	1901-2006
7	Kozhikode	282.2	17	279.3	11	1997	1901-2000
Month: September 2009							
8	Narsingpur	286	9	271.3	15	1999	1962-2009
Month: October 2009							
9	Jalpaigure	258.2	8	244.3	1	1909	1901-2009
10	Panjim	256.8	3	178.3	6	1929	1901-2009
11	Kurnool	185.9	1	147.6	17	2001	1901-2009
12	Karwar	434.0	3	190.2	13	2002	1901-2009

deaths due to heat waves in May, mainly in Andhra Pradesh.

Tropical Cyclone Aila developed as a tropical depression on 23 May in the North Indian Ocean and made landfall near the India-Bangladesh border on 25 May as a severe cyclonic storm. The storm not only affected residents but also affected the ecosystem of the Sundarbans. Dhaka, the capital city of Bangladesh, received 290 mm of rain on 29 July, the greatest rainfall in a single July day since 1949.

On 16 July, northern parts of the west coast of India received exceptionally heavy rainfall, with many stations reporting record heavy rainfall, causing large-scale flooding. On 16 July, Veraval, a coastal town in Gujarat, recorded 500 mm of rainfall in just 24 hours. During the first week of October, the southern states of Karnataka and Andhra Pradesh received their heaviest rainfall in more than 60 years, leading to one of their worst floods on record. At least 286 people were killed and 2.5 million were left homeless following the torrential downpours and subsequent flooding. Government officials reported total damages in the range of $6.7 billion U.S. On 3 October, the city of Panjim on the west coast of Goa, recorded 256.8 mm of rainfall in 24 hours, the heaviest October rainfall on record for Panjim (Table 7.1)

4) Southwest Asia

(i) Iraq—M. Rogers

Iraq, in 2009, experienced temperatures higher than the 1961–90 average across most areas and the extension of the drought which has led to falling river levels in the Tigris and Euphrates. Rainfall was generally lower than the 1949–90 average, which had a massive impact upon wheat, rice, and barley production within the country.

(A) Temperature

Averaged over the year, temperatures for Iraq were 1°C–2°C above the 1961–90 normal, although some areas in the west of the country recorded temperatures up to 1°C below average.

Mean winter temperatures were slightly above average during December 2008 and January 2009 but were around 3°C higher than average during February. For the winter as a whole, temperatures were near normal in the south but 1°C–2°C higher than normal further north. Spring temperatures were generally average during March and April but in most areas were 2°C–3°C above normal during May. The exception was in the western desert, where temperatures were below average (around 3°C below at Ar Rutbah).

Summer temperatures were 1°C–3°C above average. Again, the exception was western Iraq, with below-average temperatures (1.5°C at Ar Rutbah). The northwesterly Shamal winds dominated conditions, bringing occasional dust storms. Similarly, September–October temperatures were generally 1°C–2°C above normal, except in the West where they were near average. The year ended with temperatures 2°C–3°C above the December average.

(B) Rainfall

Rainfall over Iraq was generally less than 60% of the 1949–90 average, with significantly lower falls recorded in some regions (Fig. 7.46).

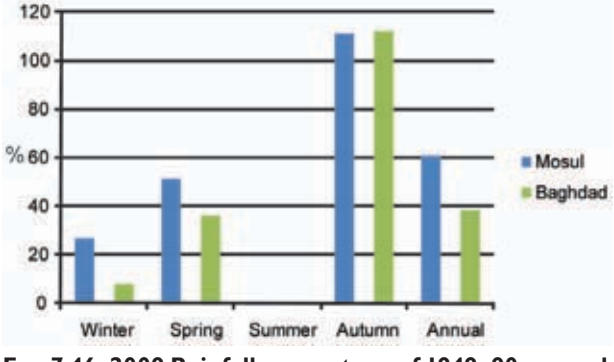


Fig. 7.46. 2009 Rainfall percentage of 1949–90 normal. (Source: U.S. Air Force, 14th Weather Squadron.)

The winter period, Iraq's wet season, was much drier than normal with most locations receiving less than 30% of their normal winter rainfall. Baghdad only recorded around 8% of its average rainfall. Rainfall in spring was also well below average, with Mosul receiving just 52% of their normal spring total and Baghdad just 36%.

However, an unsettled period of weather during September and October led to above-average rainfall in many places. Both Mosul and Baghdad recorded rainfall totals 10% higher than average during autumn, even though November was drier than normal. Mosul received over 200% of the normal rainfall during October. The rainfall in December at Mosul was just over 20% higher than expected but further south it was again drier than normal.

(C) Notable events

Due to the dry conditions lifted dust occurred more frequently across the year and fog occurred less.

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

(A) Temperature

Maximum, minimum, and mean temperature anomalies for Iran were mixed during 2009 (Table 7.2). Winter was generally much warmer than the 1989–2008 average, with temperatures around 3°C above normal and local anomalies of up to +4°C. During spring, while the northern part of the country experienced temperatures up to 2.8°C below average, the southern and western parts of Iran recorded mean temperatures up to 3°C above average (Fig. 7.47). For summer, temperatures were generally 0°C–2°C above

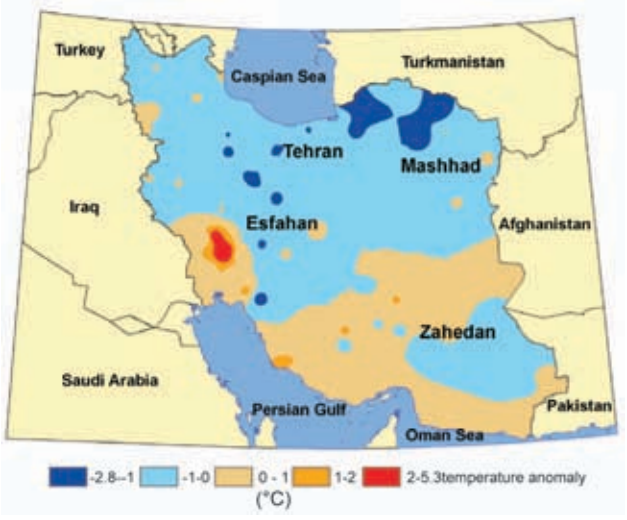


Fig. 7.47. Spring mean temperature anomaly (°C; base period 1989–2008) for Iran. (Source: Islamic Republic of Iran Meteorological Organization.)

normal; however, in the northwest of the country, average temperatures were up to 3°C below average. The largest anomalies were recorded in Dogonbadan and Amol (southeast Iran), with temperatures 3°C and 2°C below normal, respectively. Temperatures during autumn were generally warmer than average across the whole country, with anomalies around +2°C; although small areas in the South and Southeast recorded anomalies between +3 and +5°C. Only a small area of cooler-than-average conditions was confined to parts of the northwest.

(B) Rainfall

Iran was wetter than its 1989–2008 average during spring and autumn 2009 (Table 7.2), with spring, autumn, and summer receiving more rainfall in 2009 than they received during the previous year. During winter, areas with near- to above-average rainfall were confined to some parts of the Northeast (Golestan Province), the Southeast, and small areas in the Northwest of the country. At Gonbad, in Golestan province, rainfall was up to 400% of the long-term average. The largest total of 435 mm was observed in Koohrang in the Zagross mountain area. Elsewhere conditions were very dry, with precipitation at most 30% of the long-term mean. In contrast to the previous year, precipitation was generally above average during spring (Fig. 7.48). Over more than three-quarters of the country, precipitation was at least 140%, peaking over 170%, of the long-term mean. Highest totals were recorded in Bandar Abbas, which received around 300% of its normal spring rainfall.

During the summer, most of the western half of the country received above-average precipitation, while southeastern parts of the country recorded below-normal rainfall. Although rainfall totals of up to 350 mm were recorded in Astara, some areas in the South, Central, East, and Southeast received no measurable rainfall at all.

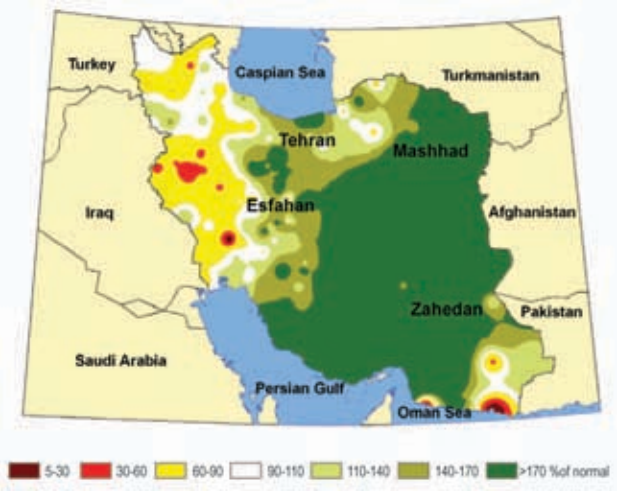


Fig. 7.48. Spring precipitation (percentage of the 1989–2008 normal) for Iran. (Source: Islamic Republic of Iran Meteorological Organization.)

During autumn, most parts of the country, except for areas in the southern half, the Northeast, and some parts of the Northwest, received up to 110% of their long-term rainfall. Highest rainfall was recorded in Zagross, in the Alborz mountain area.

(C) Notable events

Significant dust storms were reported during winter, spring, and summer, spreading out over large parts of the southern half of Iran. Unusually, these conditions extended into other parts of the country, including the Southwest and central areas, during summer.

h. Oceania

1) Australia—B. C. Trewin and A. B. Watkins

Australia experienced its second warmest year on record in 2009, featuring three exceptional and widespread heat waves. It was the warmest year on record for the states of South Australia and New South

Table 7.2. Seasonal amount of precipitation and temperature over Iran 2009

parameter	Season	Winter	Spring	Summer	Autumn
Precipitation	Average (mm)	62.6	81.0	11.5	85.5
	Respect to (%) long term	42%	36%	6%	37%
	Range from-to (mm)	0 to 435	5 to 395	0 to 350	2 to 702
Temperature	Respect to long term	0 to 3	-2 to -5.3	-2 to 3	0 to 5
	Range from-to (°C)	-5.5 to 22.5	5 to 34	15 to 39	2 to 23

Wales. The warmth was particularly marked in the second half of the year, coinciding with a transition from La Niña to El Niño conditions. Nationally-averaged rainfall was close to normal, with a very wet summer in many tropical areas being followed by generally drier-than-normal conditions from March to November.

(i) Temperature

Australia had its second warmest year on record in 2009 with a national anomaly of +0.90°C, only behind the +1.06°C record mean temperature anomaly observed in 2005. Both maximum and minimum temperatures were well above normal, with anomalies of +1.04°C (third highest) and +0.76°C (fifth highest), respectively. South Australia (mean temperature anomaly +1.26°C) and New South Wales (+1.32°C) each had their warmest year ever, breaking records set in 2007, while Victoria (+1.02°C) ranked second behind 2007.

Maximum temperatures were generally above normal almost throughout the country (Fig. 7.49). Anomalies exceeded +1°C over most of mainland Australia south of the tropics except for southern Western Australia. The largest anomalies, mostly between +1.5°C and +2°C, were in inland areas of New South Wales and southern Queensland, as well as in an area straddling the Western Australia–Northern Territory border west of Alice Springs.

Minimum temperatures were also above normal through most of Australia (Fig. 7.50), although they were below normal in most tropical areas of Queensland, as well as in scattered patches through Western Australia and the northern half of the Northern Territory. The largest anomalies (+1°C and +1.5°C), were in the southern and central inland, covering most of South Australia north of Port Augusta, New South Wales west of the Great Dividing Range, southwestern Queensland, and the southern Northern Territory.

Early in the year there were marked temperature contrasts between northern and southern Australia. January and February were much cooler than normal in most of the tropics as a result of the very active wet season. Maximum temperatures were at least 2°C below normal for the period over much of tropical Queensland and the eastern Northern Territory, reaching up to 6°C below normal near Cloncurry. In contrast, temperatures were 2°C–3°C above normal in much of southern Australia, during a period which included the major heat wave of late January and early February (see sidebar).

After being only slightly above normal (anomaly +0.28°C) for the first five months of the year, temperatures became sharply above normal from June onwards. The winter–spring (June–November) period (anomaly +1.22°C) was Australia's warmest on record by more than 0.3°C, as was the second half of the year (anomaly +1.22°C). Both August and November contained major heat waves, resulting in both months being the warmest on record for Australia (see sidebar).

The year 2009 also ended Australia's warmest decade since temperature records began in 1910, with a mean temperature 0.48°C above the 1961–90 average.

(ii) Precipitation

Rainfall averaged over Australia for the year was 458 mm (2% below normal), ranking 63rd highest since records began in 1900. Annual rainfall was above normal over most of the northern tropics and in Tasmania but was near or below normal over most of the southern and central mainland.

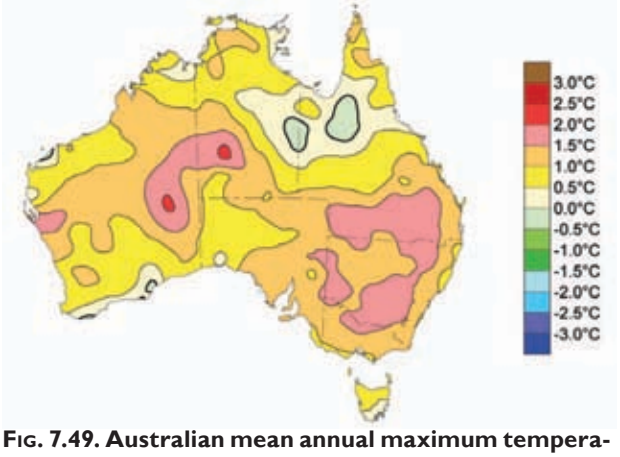


Fig. 7.49. Australian mean annual maximum temperature anomalies (base period 1961–90) for 2009.

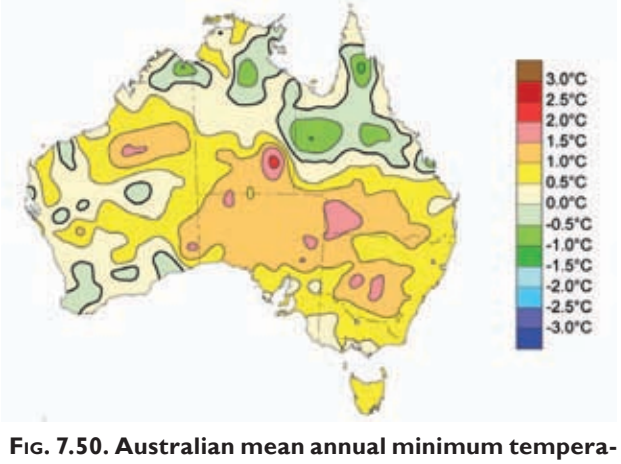


Fig. 7.50. Australian mean annual minimum temperature anomalies (base period 1961–90) for 2009.

The most significant area of above-normal rainfall was in northern Queensland (Fig 7.51), where most of the region between about 17°S and 21°S had annual rainfall in the highest decile with some areas around Mount Isa experiencing their wettest year on record. Smaller areas in the highest decile were scattered through tropical Western Australia, the Northern Territory, the West Kimberley region, the northern coast of New South Wales, and in southeastern Tasmania around Hobart.

The two most significant dry areas were in central Australia and on the southeast coast. Annual rainfall was in the lowest decile along the southeast coast and the adjacent inland region between Wollongong and Melbourne and in much of the southern Northern Territory. In northeastern South Australia, Moomba only had 11 mm from January to mid-November. There were smaller areas in the lowest decile in inland southeast Queensland and along the southern half of Western Australia's west coast (including Perth).

The bulk of the tropical rainfall fell in January and early February, with northern Queensland wet-season rainfall being the highest since 1990/91. Conditions through most northern and central areas became much drier from March onwards, and a number of locations in northwestern Queensland and the central Northern Territory had no rain between early April and late November. Wet conditions returned in December as a result of Tropical Cyclone Laurence.

The January–May period was dry across much of southern Australia, especially Victoria and southwest Western Australia, where it ranked as the third- and fifth-driest on record, respectively. Kalbarri (Western Australia) did not record its first rain of 2009 until 20 May. Rainfall returned to more normal levels from June onwards, leading to a good winter cropping season in many areas. Nevertheless, annual rainfall was 19% below normal for Victoria and 15% below normal for the Murray–Darling Basin, continuing the long-term droughts in these regions which commenced in 1997 and 2001, respectively.

Tasmania had an extremely wet winter and early spring, with June–September rainfall the second highest on record. Despite dry conditions early and late in the year, these rains were sufficient for the state's annual rainfall to be 8% above normal.

(iii) Notable events

There were three exceptional heat waves in Australia during 2009, all of which saw records broken by large margins over wide areas. The first occurred in late January and early February, affecting southeastern Australia, and was accompanied by widespread loss of life resulting from extreme heat and bushfires. Major heat waves also occurred in August in much of tropical and subtropical eastern Australia and in November in most of the Southeast (see sidebar) The heavy tropical rains early in the year resulted in widespread flooding, especially in Queensland. Floods persisted for several weeks on many rivers in northwestern Queensland. Floodwaters from the Georgina River eventually led to a partial filling of Lake Eyre. Further east, there was major flooding on a number of coastal rivers in coastal Queensland. The worst impacts were in the vicinity of Ingham, which received 949 mm of rainfall in a six day period, 30 January–4 February.

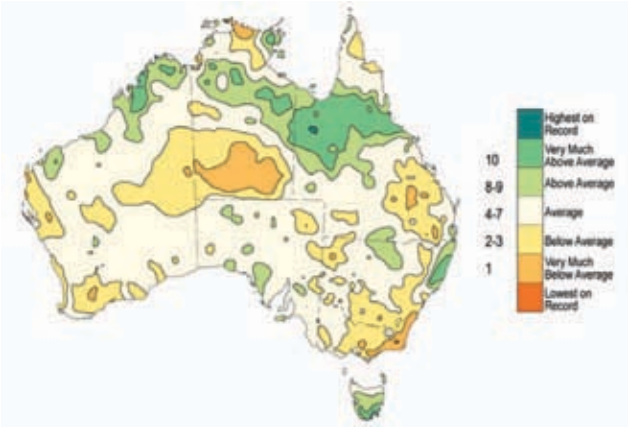


Fig 7.51. Australian annual rainfall deciles (since 1900) for 2009.

A section of the northern New South Wales coast centered on Coffs Harbour was subject to repeated flooding with five significant events during the year. The most widespread, in late May, extended north to the Clarence River catchment and parts of southeast Queensland. Property damage was mostly minor, but there was one death in the Coffs Harbour area and the town of Yamba was isolated for nine days.

At the end of the year, tropical cyclone Laurence made landfall at category 5 intensity, between Broome and Port Hedland after an earlier landfall east of Derby. Moisture from its remnants fed into an inland trough and resulted in flooding in parts of northern inland New South Wales during the last week of December.

Dust storms affected eastern Australia on a number of occasions in late September and early October. The most significant, on 22–23 September, reduced visibility to below 200 meters over a vast area, including the cities of Sydney, Brisbane, and Canberra. This is believed to be the most extensive dust storm of such intensity since at least the 1940s.

The most significant severe thunderstorms of the year affected northern Tasmania on 15 April, with some property damage and widespread power outages. A tornado passed directly over an automatic weather station at Scottsdale, with a gust of 194 km hr^{-1} recorded.

(iv) Significant statistics

- Mean annual maximum temperature anomaly: +1.04°C
- Mean annual minimum temperature anomaly: +0.76°C
- Mean annual rainfall anomaly: -3%
- Highest annual mean temperature: 29.4°C, Wyndham (Western Australia)
- Lowest annual mean temperature: 4.9°C, Mount Wellington (Tasmania)
- Highest annual total rainfall: 7440 mm, Bellenden Ker (Top Station) (Queensland)
- Highest temperature: 49.0°C, Emu Creek (Western Australia), 10 January
- Lowest temperature: -14.9°C, Charlotte Pass (New South Wales), 16 July

AUSTRALIA'S THREE GREAT HEAT WAVES OF 2009—B. C. TREWIN AND A. B. WATKINS

Australia experienced three exceptional heat waves during 2009, with records broken by huge margins and with major loss of life through both extreme heat and bushfires.

January/February-The first heat wave affected southeastern Australia on 27 January–8 February. Between 27 January and 31 January, the state capitals Adelaide and Melbourne had four and three consecutive days, respectively, above 43°C, both of which were records. Large areas of southern Victoria and Tasmania set all-time records. A new state record for Tasmania was set with 42.2°C at Scamander on the 30th. Extreme day and nighttime heat (including a record high minimum of 33.9°C at Adelaide on the 29th) caused severe heat stress, with 374 excess deaths occurring in Victoria. Extreme heat returned to South Australia on 6 February and to Victoria and New South Wales on the 7th (Fig. 7.52), with an all-time record of 46.4°C at Melbourne and a Victorian state record of 48.8°C at Hopetoun. Of 35 long-term stations in Victoria, 24 set all-time records; six others set February records. The accompanying strong, dry northwesterly winds fanned bushfires which claimed 173 lives, mostly in areas northeast of Melbourne.

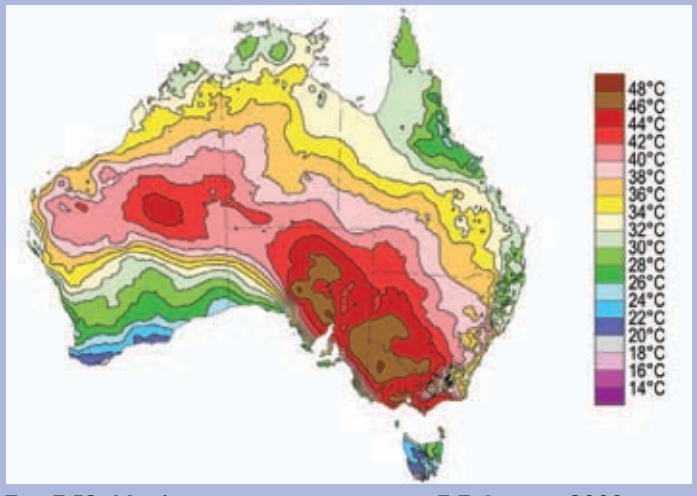


Fig. 7.52. Maximum temperatures on 7 February 2009.

August-Forty-nine percent of the continent, including most of Queensland and the Northern Territory, experienced its highest August mean maximum temperature on record, resulting in a new all-time record national maximum temperature anomaly of +3.20°C. Extreme heat occurred on 14–16 August, 21–25 August, and 29–30 August. A New South Wales August record of 37.8°C was set on the 24th at Mungindi, while a new Queensland record of 38.5°C was set on the 29th at Bedourie. Site records were broken by extremely large margins with numerous long-term stations setting August records by more than 4°C. Daily maximum temperature records were set over 25% of Australia, including 55% of Queensland.

November-Persistent heat occurred across much of southeast Australia. All-time duration records were set in South Australia at Port Lincoln (eight consecutive days above 30°C) and Murray Bridge (six consecutive days above 40°C); these were particularly extraordinary as extended heat waves in southern Australia have been almost entirely confined to the second half of summer and early autumn. Adelaide's eight consecutive days above 35°C was double its previous November record. Daily record high temperatures for November occurred over 41% of New South Wales, including a state November record of 46.8°C at Wanaaring on the 20th. The mean monthly temperature anomaly for New South Wales was +4.61°C, the largest recorded for any Australian state, with Victoria (+4.36°C) also breaking the previous record. (In Victoria, only one December has been hotter than November 2009). Eighty long-term stations had their largest monthly maximum temperature anomaly on record for any month, and Cowra's anomaly of +7.9°C was the largest recorded at any Australian station since 1914.

- Highest one-day rainfall: 510 mm, Urunga (New South Wales), 1 April
- Highest wind speed (measured): 211 km hr^{-1}, Mandora (Western Australia), 21 December

2) New Zealand—G. M. Griffiths

New Zealand's climate for 2009 was characterized by frequent seesaws in extreme temperature. Heat waves occurred in January and the start of February; May was the coldest on record; August was the warmest August since records began; and October had its lowest temperatures since 1945. During individual months (notably September and November), daily maximum and minimum temperatures frequently broke long-standing records, with extremely cold temperatures often occurring within a week or so of record hot events. The decade 2000–09 was the warmest in the instrumental record for New Zealand.

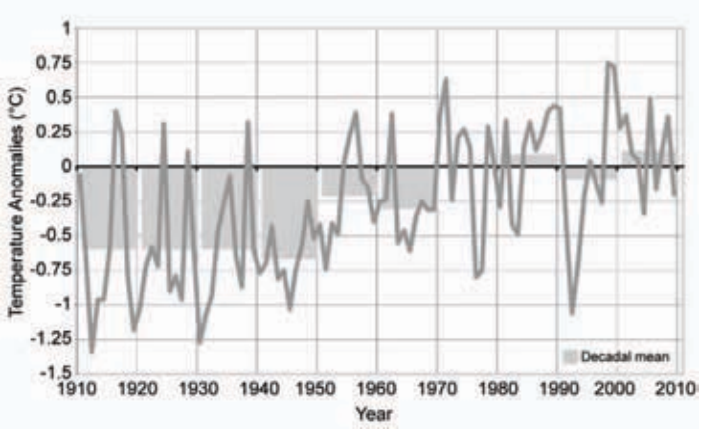


Fig. 7.53. Annual and decadal mean temperature anomalies for New Zealand based upon a seven-station series. Base period: 1971–2000.

(i) Temperature

The New Zealand national average temperature[2] for 2009 was 12.42°C, 0.16°C below the 1971–2000 normal (Fig. 7.53), consistent with the prevailing southwesterlies over the country during the year. Temperatures were generally within 0.5°C of the long-term average over most of the country. The exceptions were parts of Auckland, Waikato, Manawatu, southern Hawkes Bay, Wairarapa, Wellington, Marlborough, inland Canterbury, and eastern Otago, where annual temperatures were 0.5°C–1.0°C below average.

The year was notable for two remarkably warm months (January and August) and a very warm spell in early February. Heat waves were experienced over the country 7–12 February, when northwesterlies transported some of the record-breaking Australian heat to New Zealand. Temperatures of 34°C or more occurred in many locations on each day in this period. Many new records of extreme high monthly maximum temperatures were established in January, February, and August. In contrast, New Zealand also experienced four extremely cold months (March, May, June, and October), and an extended frosty period across many parts of the country on 16–26 June. Many record-low monthly minimum temperatures were established in these four months, as well as numerous record-low daily minimum temperatures.

The decade 2000–09 was the warmest in the instrumental record for New Zealand, with a 10-year average temperature of 12.69°C, 0.11°C above the long-term normal, just surpassing the previously warmest decade (the 1980s).

(ii) Precipitation

Annual rainfall for 2009 was below normal (50%–80% of normal) for parts of Auckland, the central North Island, and eastern areas of both islands (northern Hawkes Bay, southern Wairarapa, north Canterbury, inland south Canterbury, and central Otago). Taupo, in the central North Island, recorded its driest year since records began in 1949 (712 mm). Elsewhere, annual rainfall was near normal.

The year 2009 was unusually snowy in New Zealand, with an extended snow season that started in April and finished in October. Numerous and heavy snowfall events, and the record warmth of August, contributed to a high-risk avalanche season in the Southern Alps in August and September. Major snowfall events to low levels, which were widespread, were observed on 31 May, 16 June, 2–5 July, and 4–6 October, resulting in significant community impacts. The exceptionally heavy snow event on 4–5 October affected Hawkes Bay and the Central North Island and was estimated to be the worst in October since 1967, stranding hundreds of travelers, closing roads, and resulting in heavy lambing losses. Snowfall was also observed in Taranaki, Waikato, and Rotorua on the 6th, for the first time in about 30 years.

The most unusual precipitation event of the year was a coating of red Australian dust, sometimes 2

[2] http://www.niwa.co.nz/news-and-publications/news/all/nz-temperature-rise-clear/seven-station-series-temperature-data

mm thick, which fell on parts of Northland, Auckland, Waikato, Bay of Plenty, and Taranaki on 25 September.

(iii) Notable events

At the start of 2009, soil moisture levels were below normal for much of the North Island (except Gisborne and northern Manawatu), as well as in the Tasman District, northern Westland, north and south Canterbury, and south Otago. However, rainfall in late February returned soil moisture levels to near-normal status across much of the country. For regions in the north and east of the North Island, and eastern South Island (Northland, Auckland, Coromandel, Bay of Plenty, central North Island, Gisborne, Hawkes Bay, Otago, Canterbury, the Kaikoura coast), severe soil moisture deficits had again developed by the end of the year, following an extremely windy and dry November and December period. Northland was particularly affected. The geographical pattern of significant soil moisture deficits in northern and eastern areas seen at the end of 2009 is a typical impact of El Niño conditions for New Zealand.

There were 15 flooding events in New Zealand in 2009, slightly less than 2008. Major flooding occurred on 27 April on the West Coast. On that day, Mt. Cook recorded 341 mm of rainfall (its highest April one-day total since records began in 1928), and torrential rain fell in Greymouth, where roads became impassable and homes were evacuated. Trampers were stranded in the Mueller Hut in Aoraki Mt. Cook National Park, and about 120 people were evacuated from the Milford Track by helicopter. Heavy rains also caused flooding on 16–20 May in the Canterbury and Otago regions, when the Rangitata River burst its banks. On 29 June, heavy rain resulted in landslips and road closures in the Manawatu–Wanganui region. Heavy rainfall in the Gisborne District on 29 and 30 June led to flooding, evacuations, landslips, and the declaration of a Civil Defence Emergency.

(iv) Significant statistics

- Highest annual mean temperature: 15.8°C, Whangarei (Northland)
- Lowest annual mean temperature: 7.3°C, Mt. Ruapehu (central North Island)
- Highest annual rainfall total: 10 956 mm, Cropp River in the Hokitika River catchment (West Coast)
- Highest one-day rainfall: 341 mm, Mount Cook, 27 April
- Highest recorded air temperature: 38.0°C, Culverden (Canterbury), 8 February (Also highest February maximum temperature ever recorded at this location)
- Lowest recorded air temperature: -11.7 °C, Middlemarch (Central Otago), 19 July
- Highest recorded wind gust: 184 km hr^{-1}, Southwest Cape, Stewart Island, 4 November

3) Southwest Pacific—A. Peltier and L. Tahani

Countries considered in this section include: American Samoa, Cook Islands, Fiji, French Polynesia, Kiribati, Nauru, New Caledonia, Niue, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, and Vanuatu.

(i) Temperatures

Temperatures were below the 1971–2000 average at numerous stations in the equatorial Pacific during the austral summer, the result of the weakening La Niña event in the tropical Pacific. In contrast, an extended region of above-average air temperature encompassed northern Papua New Guinea, New Caledonia, Vanuatu, Fiji, Tonga, Southern Cook Island, and the Austral Islands with anomalies up to +1.8°C south of Rapa (150°W).

With the development of El Niño in the austral winter, the temperature pattern reversed, with above-average air temperatures near the equator and relatively low temperatures over New Caledonia, Vanuatu, and Fiji. In general, temperatures were above normal in 2009 (Fig. 7.54; Table 7.3), largely due to the early-year La Niña being relatively weak compared to the subsequent moderate 2009/10 El Niño.

(ii) Rainfall

Annual rainfall exceeded 120% of the 1979–95 mean over parts of New Caledonia and Vanuatu (Fig. 7.55; Table 7.4). Below-normal precipitation (< 80%)

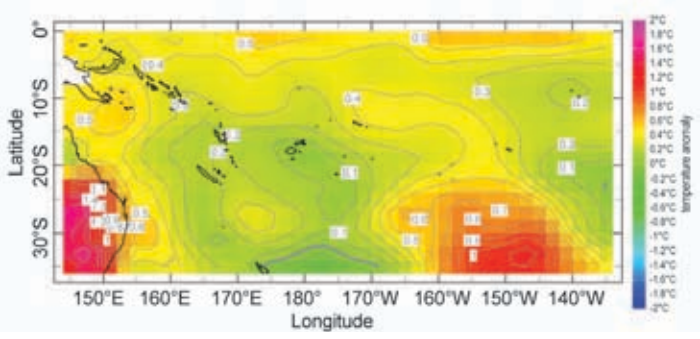


Fig. 7.54. Air temperature anomaly (1971–2000 base period) for the Southwest Pacific. (Source: NOAA NCEP CPC CAMS.)

Table 7.3. Average temperature anomaly (°C relative to 1971–2000 base period) for 2009 recorded by Pacific Islands Met Services. (Source: NOAA/NCEP CPC CAMS.)

Station	Island	2009 Anomaly
Pekoa Airport (Santo)	Vanuatu	+0.4
Noumea	New Caledonia	+0.6
Rotuma	Fiji	+0.1
Nadi Airport	Fiji	+0.2
Hihifo	Wallis	+0.6
Rarotonga	Cook Islands	-0.3
Tahiti-Faaa	Society Islands	+1.4
Takaroa	Tuamotu Islands	+0.5
Rapa	Austral Islands	+0.9
Norfolk Island Aero	Australia	+0.3

was recorded over Gambier and Tuamotu islands and along the equator across western Kiribati, Tuvalu, Tokelau, and eastern Kiribati. For the second year in a row, Tarawa and Banaba islands were particularly affected by significant drought conditions during the first six months of the year, highlighted by a number of record-low rainfall totals. Rainfall from January to April was above average over the Solomon Islands, Vanuatu, New Caledonia, Fiji, Tonga, Niue, and the Southern Cook Islands, while rainfall deficits were significant along the equator and over French Polynesia.

The rainfall pattern observed over the Southwest Pacific was heavily influenced by the state of ENSO. During the first three months of 2009 convection was suppressed along the equator from west of Nauru across Western Kiribati to the date line, while the South Pacific Convergence Zone (SPCZ) was further south and west of its mean location, extending from Papua New Guinea and northeastern Queensland to the New Caledonia archipelago (165°E). This La Niña dipole was less intense, and the area of maximum convective activity was not as spread out as during 2008, when the La Niña event resulted in the SPCZ expanding as far southeast as the Southern Cook Islands (160°W). In April 2009, the SPCZ shifted eastward, contributing to enhanced convective activity from Wallis and Futuna (175°W) to the Austral Islands (150°W). In May, the SPCZ weakened significantly, stalling over parts of Vanuatu, New Caledonia, and Fiji, southwest of its normal position. Concurrently, a zone of suppressed deep convection was present near Western Kiribati and south of the equator, extending east through Nauru and Eastern Kiribati. From June to October, the SPCZ stagnated southwest of its normal position and contracted toward Northern Papua New Guinea. Enhanced convection was largely absent from the region during the austral winter, while the area of suppressed convection contracted towards the central part of the Southwest Pacific, near Tokelau. During November and early December, above-average convective anomalies along a southwest-displaced SPCZ were seen near northern Vanuatu, northern Queensland, and the eastern edge of Papua New Guinea, before becoming established eastward across Western Kiribati, Fiji, Tonga, Austral Islands, and the Pitcairn Islands as El Niño conditions took hold. Suppressed convection was observed during November in the central part of the Southwest Pacific near Fiji and Samoa, before extending towards the northern Cook Islands and French Polynesia during December.

(iii) Notable events

From January to March, under the influence of La Niña conditions, stronger-than-usual easterly surface winds prevailed along the equator across the Kiribati archipelago. From May until the end of the year, the trade winds weakened and hence westerly wind anomalies covered large portions of the equatorial Pacific, with the exception of some areas near the date line.

Fourteen synoptic-scale low-pressure systems formed in the Southwest Pacific in 2009. In January, record-breaking rainfall was recorded in Viti Levu

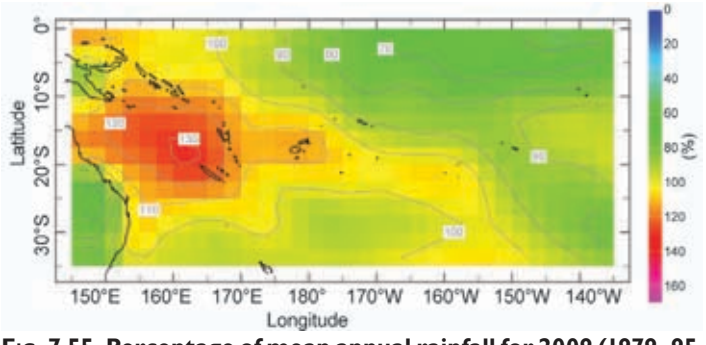


Fig. 7.55. Percentage of mean annual rainfall for 2009 (1979–95 base period) for the Southwest Pacific. (Source: NOAA NCEP CPC CAMS.)

and Vanua Levu islands (Fiji) as a consequence of a hovering monsoonal trough, an enhanced South Pacific Convergence Zone (SPCZ), two tropical depressions, and Tropical Cyclone Hettie. A total of 14 stations recorded at least 700 mm of rainfall during January, seven of them collecting more than 1000 mm. Overall, 75% of rain gauges in the Western, Central, and Eastern Divisions of Fiji recorded 200% of their average January rainfall. The related flooding is considered to be the country's worst in over 75 years, claiming 12 lives and causing substantial damages to agricultural crops, road, electricity, and water infrastructure.

In December, category 2 Tropical Cyclone Mick lashed the islands of Yasawa and Viti Levu, Fiji. On 14 December, sustained wind speeds of up to 81.3 km hr^{-1} and gusts that reached 107.2 km hr^{-1} were recorded at Nausori Airport near Suva. Five deaths and severe damage to crops and livestock were reported.

Typical of La Niña conditions, positive sea surface temperature anomalies were present around Vanuatu, New Caledonia, west and south of Fiji, and southern French Polynesia early in the year. From April to June, SSTs cooled in the Southwest Pacific, while positive anomalies developed in the western equatorial Pacific after May. In October, the warm anomalies in the western Pacific dissipated and warm anomalies developed south of French Polynesia. In December, a large area of positive anomalies, with the central region exceeding +3°C, existed from 160°W–90°W and 30°S–65°S.

Positive sea level anomalies existed in the Southwest Pacific in January from Papua New Guinea southeast to the Southern Cook Islands. Anomalies just east of Papua New Guinea exceeded +25 cm, while monthly mean sea levels at Fiji and Tonga were the highest on record. Monthly mean sea level at Fiji for February was, for a second month in a row, the highest on record. Tropical Cyclone Lin brought elevated sea levels to Tonga on 4 April 2009. Sea level at the height of the storm was 0.5 m higher than the predicted tide. Positive anomalies developed in the Southwest Pacific in May and extended almost to Rapa Island. In June, positive anomalies in the Southwest Pacific contracted both in area and magnitude but then expanded in July in the Southwest Pacific to the Southern Cook Islands. By September, the area with positive anomalies in

Table 7.4. Annual rainfall for 2009 reported by Pacific Islands Met Services

Station	Island	2009 Rainfall	Annual Mean (1979–95)	Percent of Mean
Pekoa Airport (Santo)	Vanuatu	3003	2452	122%
Koumac	New Caledonia	1529	995	415%
Noumea	New Caledonia	1129	1074	105%
Tarawa	Kiribati	2272	2302	99%
Rotuma	Fiji	3851	3515	110%
Nabouwalu	Fiji	3676	2130	173%
Nadi Airport	Fiji	2799	1708	164%
Vunisea	Fiji	2358	2047	115%
Hihifo	Wallis	2819	3218	88%
Maopopo	Futuna	4861	3206	152%
Apia	Samoa	2331	2770	84%
Pago Pago	American Samoa	3479	3003	116%
Rarotonga	Cook Islands	1657	1829	91%
Atuona	Marquesas Islands	1356	1677	81%
Tahiti-Faaa	Society Islands	1396	1690	83%
Takaroa	Tuamotu Islands	1129	1592	71%
Rikitea	Gambier Islands	1728	1994	87%
Tubuai	Austral Islands	1777	1843	96%
Rapa	Austral Islands	2865	2560	112%
Lord Howe Island Aero	Australia	1194	1483	81%
Norfolk Island Aero	Australia	901	1302	69%

the Southwest Pacific had contracted to between Australia and the Tonga and the maximum anomaly was just above +15 cm. Further weakening occurred in October in the southwest Pacific. Monthly mean sea levels were the highest on record in October at Kiribati and the highest since 2001 at Nauru.

4) Northwest Pacific, Micronesia—C. Guard and M. A. Lander

Countries considered in this section include: the Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia, the Marshall Islands, Palau, and the U.S.-affiliated Islands of Micronesia.

This assessment covers the area from the date line west to 130°E, between the equator and 20°N. It includes the U.S.-affiliated Islands of Micronesia, but excludes the western islands of Kiribati. The climate of the region is strongly influenced by ENSO. The first few months of 2009 began as La Niña, switching to El Niño by the boreal summer, becoming moderate to strong by December. After two years with virtually no tropical cyclone activity in Micronesia, the monsoon trough and tropical cyclone genesis regions shifted eastward, typical of their response to El Niño ocean patterns. In August two super typhoons impacted some of the Micronesian islands. The high sea levels characteristic of 2008 began to fall by September 2009 in response to El Niño. This process continued for the remainder of the year as oceanic heat content was transported eastward toward South America.

(i) Temperature

Average monthly maximum temperatures from January through June generally mirrored those conditions expected during moderate La Niña conditions and the transition to ENSO-neutral conditions. Average monthly maximum temperatures from January through June were generally typical of those expected during moderate El Niño events (Table 7.3). Average maximum temperature values at Yap were 0.53°C below normal (cooler and cloudier) for the first six months and 0.65°C above normal (warmer and clearer) for the latter half of the year as cloud systems developed farther eastward. Likewise, Pohnpei experienced January–June anomalies of +0.08°C and July–December anomalies of +.0.55°C, suggesting clearer and warmer conditions. Still farther east, maximum temperature anomalies at Kosrae for January–June anomalies were -0.74°C, reflecting both enhanced cloudiness from the boreal spring trade wind trough and enhanced cooling due to evaporation from the strong trade winds. The July–December temperature anomaly was -0.65°C, as the near-equatorial trough became established and produced persistent cloudy conditions. At the eastern end of the region, Majuro in the southern Republic of the Marshall Islands (RMI), had near-normal January–June average maximum temperature anomalies of +0.18°C and relatively normal July–December anomalies of +0.04°C. Average minimum temperatures in the RMI were generally warmer than normal during the year, reflecting warmer-than-normal SSTs in the region.

(ii) Precipitation

Precipitation at the major island stations during 2009 was fairly typical of La Niña conditions early in the year and El Niño conditions during the second half of the year (Fig. 7.56; Table 7.5). In the first half of the year, the western half of the basin was wetter than normal, while most of the islands east of 155°E were drier than average. However, the stronger-than-normal and converging northeast and southeast trade winds typical of La Niña events allowed the trade wind trough to become well developed, keeping the western North Pacific islands between 3°N–6°N wet during the first half of the year. The trough axis typically passes very close to Kosrae, which had 2577.1 mm or 108% of normal rainfall during the first half of 2009. Generally throughout Micronesia, rainfall for

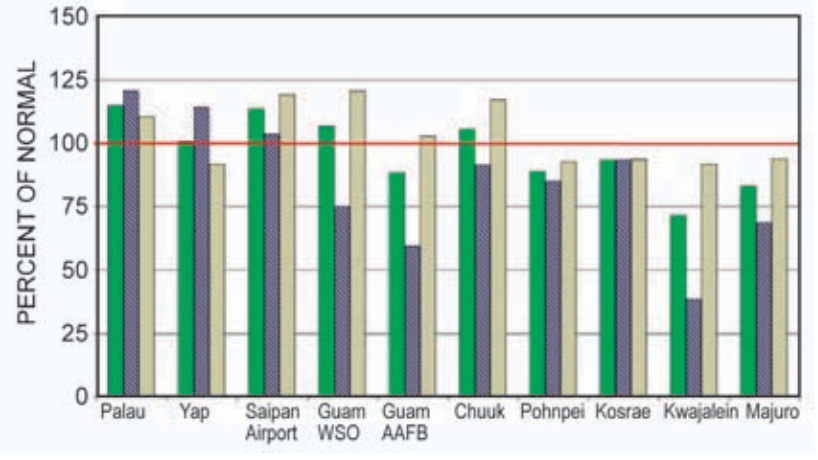


Fig. 7.56. Rainfall as a percent of normal for selected Micronesian islands for January through June (solid green), July through December (hatched blue), and for January through December 2009 (solid tan). The percent of normal is determined from the NCDC 1971–2000 base period.

Table 7.5. Maximum temperature anomalies and rainfall anomalies for selected Micronesian locations for January through June 2009 (Jan–Jun) and for July through December 2009 (Jul–Dec). "N" is the normal rainfall taken from the NCDC 1971–2000 base period. Locations (lat and lon) are approximate.

Location	Max Temp		Rainfall							
	Jan-Jun	Jul-Dec	Jan-Jun			Jul-Dec			Jan-Dec	
	°C	°C	N mm	2009 mm	%	N mm	2009 mm	%	2009 mm	%
Saipan 15°N 146°E	NA	NA	414.8	502.9	212	1293.1	1521.0	118	2023.9	120
Guam 13°N 145°E	+0.25	-0.13	612.1	525.0	86	1555.5	1942.1	126	2467.1	114
Yap 9°N 138°E	-0.53	+0.65	1168.9	1356.9	116	1818.6	1707.4	94	3064.3	103
Palau 7°N 134°E	+0.01	-0.64	1724.7	2020.1	117	2043.9	2300.2	113	4320.3	115
Chuuk 7°N 152°E	-0.21	-0.54	1538.0	1427.5	93	1864.9	2169.9	116	3597.4	106
Pohnpei 7°N 158°E	+0.08	+0.55	2277.6	1941.8	85	2411.5	2318.3	96	4260.1	91
Kosrae 5°N 163°E	+0.40	+0.22	2387.3	2577.3	108	2128.8	2313.5	109	4890.8	109
Majuro 7°N 171°E	+0.18	+0.04	1455.4	970.3	67	1888.7	1796.8	95	2767.1	82
Kwajalein 9°N 168°E	+0.03	+0.06	959.6	381.0	40	1590.5	1468.9	92	1849.9	73

the first six months, for the last six months, and for the entire year of 2009 fell between 75% and 125% of average. Only the eastern-most part of Micronesia fell outside this bracket, with extremely dry conditions experienced at Kwajalein (40% of average) and very dry conditions at Majuro (67% of average) during the first half of the year. Rainfall in the RMI increased to near-normal levels (95% at Majuro and 92% at Kwajalein) during the second half of the year as the monsoon trough pushed eastward. For the year as a whole, locations west of 155°E were wetter than normal and areas east of that longitude were drier. The annual rainfall for the major islands in Micronesia ranged from a high of 4890.1 mm (108%) at Kosrae to a low of 1849.9 mm (73%) at Kwajalein in the RMI. Palau at the western edge of the area had 4320.3 mm or 115% of normal, while Majuro at the eastern edge of the area had 2767.1 mm, 83% of normal for the year. In the center of Micronesia, Chuuk had 116% of its normal rainfall during the second half of the year and 106% for the entire year. Table 7.5 shows the annual rainfall amount and percent of normal for the major Micronesian islands.

(iii) Notable events

The high sea levels that prevailed in 2007, 2008, and early 2009 finally began to fall by midyear as El Niño conditions reduced the easterly wind stress that caused water to mound up in the west of the basin. In the first three months of the year, coastal flooding and inundation affected many of the low islands from the Marshall Islands in the East to Palau in the West. From January through March 2009, sea levels averaged 15 cm–25 cm above their normal monthly averages, but during full and new moon phases, the high-tide levels were sometimes as high as 80 cm–110 cm above their normal monthly averages. The high astronomical tides coupled with the effect of La Niña and the long-term rising trend in sea level caused considerable coastal inundation in Chuuk State and in the Marshall Islands, contaminating drinking water and destroying crops. Weakened trade winds, starting

in April, triggered Kelvin waves which depressed the thermocline east of the dateline, resulting in higher ocean heat content and thus elevated sea level toward the Central and South American coasts. Correspondingly, this reduced ocean volume in the equatorial western Pacific, causing sea levels there to fall.

Tropical cyclone activity in 2009 across Micronesia increased considerably from 2008 (see chapter 4), as the El Niño conditions caused tropical cyclone genesis to occur farther to the east into central Micronesia. Super typhoons Choi-wan and Melor were the most notable, with Choi-wan devastating Alamagan Island (17.60°N, 145.85°E) in the Northern Mariana Islands and forcing the post-storm evacuation of the 14 residents.