STATE OF THE CLIMATE IN 2011

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STATE OF THE CLIMATE IN 2011

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7. REGIONAL CLIMATES—A. Sánchez-Lugo, J. A. Renwick, W. M. Thiaw, and S. J. Weaver, Eds.

a. *Overview*—A. Sánchez-Lugo, J. A. Renwick, W. M. Thiaw, and S. J. Weaver

This chapter provides a summary of regional climate conditions—primarily temperature and precipitation—across the globe during 2011, and highlights notable weather events. The chapter is divided into seven main sections: North America, Central America and the Caribbean, South America, Africa, Europe, Asia, and Oceania. Information for a specific region has been provided by local scientists, and the source of the data used is typically the agency affiliated with the authors, unless otherwise noted. Information from 2010 may be included in some instances to accurately cover relevant climate seasons, such as the austral summer and boreal winter seasons.

In summary, North America weather conditions were characterized by strong seasonal and regional variability in precipitation and temperature. Notable events include the United States tornado outbreaks, flooding in Canada, and wildfires in Mexico. Across Central America, two tropical systems caused significant economic losses. In the Caribbean, precipitation patterns were greatly influenced by the La Niña event, resulting in a "very wet" dry season for several islands. Across South America, above-average precipitation was observed across northern parts of the continent throughout the year, with below-average precipitation across the southern regions. Of note were the deadly floods in Brazil—the worst natural disaster in the country's history. Africa was marked by extreme events that triggered humanitarian crises. The drought in East Africa in 2011 was one of the worst in several decades. Across Europe, the European drought was one of the worst events in the century. Russia experienced up to 10°C above-average temperatures on several occasions throughout the year, with the most notable warmth in March where some areas were as much as 20°C above average. Also of note was the extremely wet two-year period Australia experienced after a decade-long dry period.

For varying reasons, contributions from Egypt, Madagascar, Iraq, and the southwest Pacific were not received this year and thus are not included in this supplement.

b. *North America*

1) Canada—R. Whitewood and D. Phillips

Nationally, 2011 was the eighth warmest year on record since records began in 1948. Winter (DJF 2010/11), summer, and autumn were warmer than normal, with spring close to normal. Canada experienced its 15th driest year in 2011. Winter, spring, and autumn were all drier than normal, whereas summer was wetter than normal.

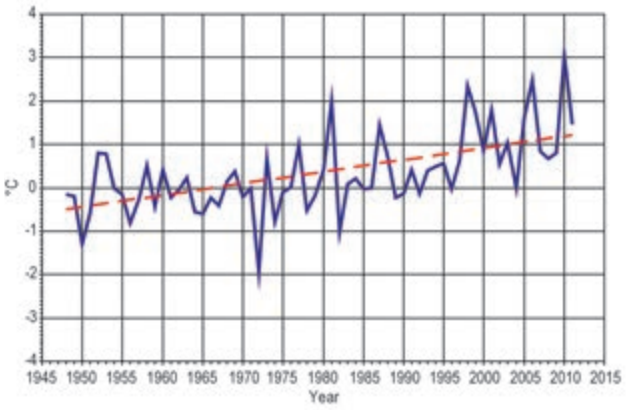

Fig. 7.1. Graph of annual mean temperature anomalies (°C) from 1961–90 normal for Canada 1948–2011.

(i) Temperature

The national average temperature for 2011 was 1.5°C above the 1961–90 base period, marking the eighth warmest year since national records began in 1948 (Fig. 7.1). Figure 7.1 also shows that the national annual average temperature has undergone a linear increase of 1.6°C over the 64-year period and that it has been at or above normal since 1993. Much of Canada's warmth was in the north, where temperatures were more than 2°C above normal, while southern British Columbia, Alberta, and Saskatchewan had temperatures close to normal in 2011 (Fig 7.2).

The Canadian winter (December 2010–February 2011) was the sixth warmest on record since 1948 with a national average temperature of 2.5°C above normal. This was especially noteworthy over the

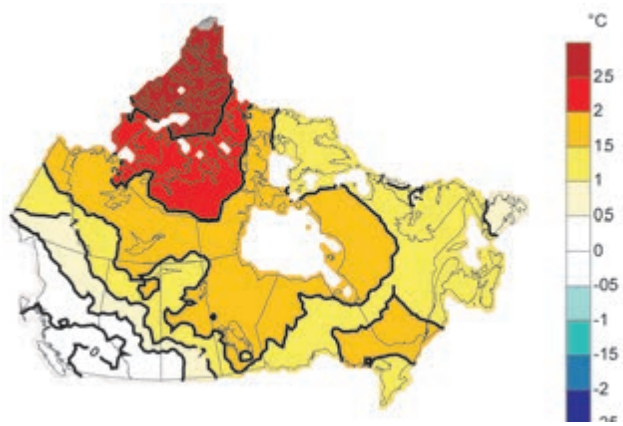

Fig. 7.2. Map of 2011 annual mean temperature anomalies (°C) from 1961–90 normal period for Canada.

northern portions of Canada as some areas of the Arctic and northern Quebec had temperature anomalies of more than 5°C above normal.

Spring 2011 was the only season this year with cooler-than-normal temperatures, although only 0.1°C below normal (within the bounds of statistical uncertainty), ranking as the 29th coldest spring since 1948. Most of these negative anomalies occurred from British Columbia, through the Prairies, and into the northern territory of Nunavut. The national average temperature for the summer of 2011 was 1.2°C above normal, which makes this the fourth warmest summer since 1948. Autumn 2011 was the third warmest autumn with a national average temperature of 2.2°C above normal.

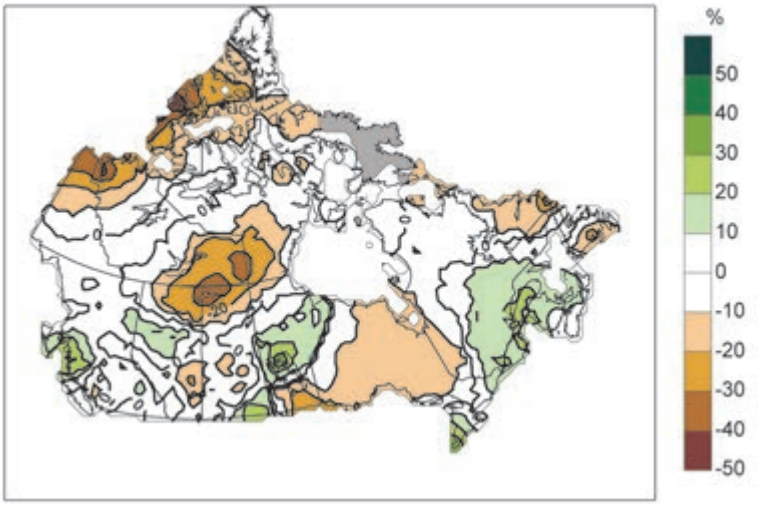

Fig. 7.4. Map of 2011 annual total precipitation percent departure from the 1961–90 normal period.

(ii) Precipitation

Overall, Canada experienced a drier-than-normal year in 2011 (5% below normal), ranking 15th driest in the 64-year period of record. This was also the first year since 1998 with a drier-than-normal national average and was the driest since the persistent wet anomalies which began in 1970 (Fig. 7.3). Most of the drier-than-normal conditions occurred in the northern Yukon, Northwest Territories, and northern Saskatchewan and Alberta, with many regions indicating precipitation that was 80% of normal (Fig. 7.4). Conversely, the Maritimes, southern Ontario, central Manitoba, and the coastal areas of British Columbia experienced precipitation that was at least 120% of normal.

Winter 2010/11 was slightly drier than average, at 97.5% of normal. Areas of below-normal precipitation include the southern Prairies, Ontario, northern Yukon and Northwest Territories, and southern Nunavut and Northwest Territories, while wetter-than-normal conditions prevailed in northern Nunavut, northern Alberta, and the Maritimes.

Spring 2011 was 87% of normal (eighth driest), however, with substantial regional variability. From the Prairies northward to the Arctic, conditions were drier than normal, while southern portions of British Columbia, Manitoba, Ontario, Quebec, and New Brunswick were all at least 120% of normal.

Summer 2012 was the only season with above-normal precipitation for Canada, (109% of normal, seventh wettest). The Yukon, Northwest Territories, northern Prairie Provinces, northern Ontario, most of Quebec, and the Maritimes experienced precipitation at least 140% of normal, while most of Nunavut and southern Manitoba experienced conditions that were less than 60% of normal.

Autumn saw the return to drier-than-normal conditions for Canada, 90% of normal, ranking as the 10th driest autumn since national records began in 1948, as the Prairies, northern Yukon, and the Northwest Territories experienced precipitation that was no more than 60% of normal. Only southern Ontario had above-normal precipitation at 140%.

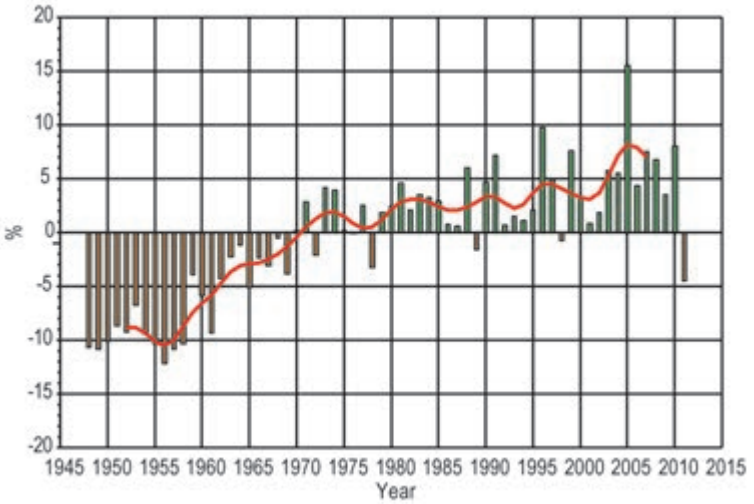

Fig. 7.3. Graph of 1948–2011 annual total precipitation percent departure from 1961–90 normal for Canada.

(iii) Notable events

Precipitation this year resulted in a record amount of flooded acreage across central Canada. Officials warned that conditions were ripe for one of the most disastrous spring floods in years, given that several Manitoba lakes and rivers were already near their highest levels ever. Cold temperatures throughout the winter resulted in deep soil-frost penetration, meaning that spring melt water would be prohibited from soaking into the ground. When spring arrived, temperatures remained cold, slowing the inevitable high snowpack melt. Heavy spring rains and snow fell, raising water levels on many of Manitoba's major rivers and lakes. The Red River peaked in Winnipeg on 7 April as the result of an ice jam driving up the water levels. The high stage ranked as the third largest in the last 150 years.

On 9 May the Assiniboine River reached its highest level since 1923 in the city of Brandon, nearly seven meters above average and 20 to 30 times wider in some places. This flooding lasted 120 days and was the largest on record. An estimated 7100 Manitobans were displaced from their homes, with 2700 unable to return by year's end. Flooding swamped three million hectares of farmland and local states of emergency were declared in 70 Manitoba communities. In addition, flood waters forced the closure of 850 roads, including parts of the Trans-Canada Highway.

The spring also brought flooding to southern Quebec, likely the worst for the province since Confederation in 1867. The spring thaw led to swelling rivers that empty into Lake Champlain. Adding to the high water were intense rains, pushing water levels to record highs for 37 days in a row. The overflow moved down the Richelieu River, breaching river banks and flooding hundreds of farms. Losses were estimated at more than $78 million (US dollars).

On 21 August, a waterspout came ashore in Goderich, Ontario. Once on land, this tornado caused damage comparable to an EF-3, as measured in the US, causing extensive damage while killing 1 person and injuring 40 others. The Insurance Bureau of Canada estimated that the insured damage exceeded $100 million (US dollars).

In western Canada, conditions around the northern Alberta community of Slave Lake were primed for a potentially dangerous fire season in the late spring. A fire broke out on 15 May and spread rapidly due to the 100 km hr^{-1} winds. Racing through Slave Lake at 4.2 km hr^{-1}, the wildfire led to the evacuation of 7000 residents. One-third of the homes and businesses in Slave Lake (about 400 structures) were incinerated in the ~1000°C heat. The Insurance Bureau of Canada reported the Slave Lake wildfire was the second costliest natural disaster in Canadian history at more than $700 million (US dollars), $400 million of which were uninsurable losses.

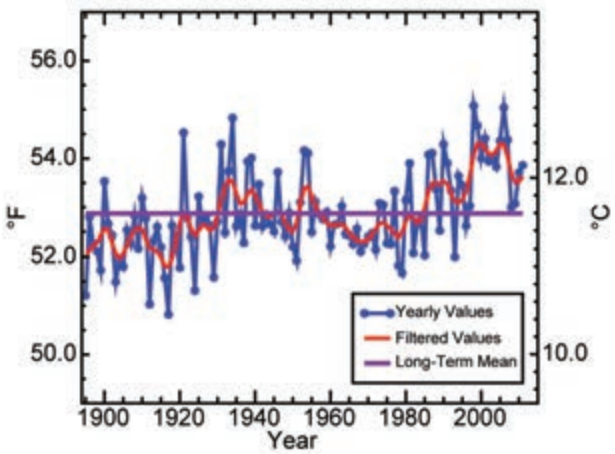

Fig. 7.5. Annual mean temperature (°C) for the contiguous U.S. for the period 1895–2011. The filter is a weighted average that is used to smooth the year-to-year changes in the data values that may help identify the presence/absence of trends throughout the data record. (Source: NOAA/NCDC)

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

Based on preliminary data, the annual average temperature in 2011 for the contiguous United States was 12.2°C, which is 0.6°C above the long-term (1901–2000) average, tying for the 22nd warmest year since records began in 1895 (Fig. 7.5). The nationally-averaged precipitation during 2011 was slightly below average and ranked as the 51st driest year on record. However, the nationally-averaged value masked regional extremes.

(i) Temperature

Anomalous warmth dominated much of 2011. As shown in Fig. 7.6a, the 2011 temperature pattern on a statewide level consisted of positive anomalies throughout much of the country. The winter season (December 2010–February 2011) was marked by anomalously cold temperatures across the eastern half of the country. Conversely, the winter season across the western US was near average, with only the West climate region experiencing winter temperatures that were above average. Regional spring (March–May) temperatures were above normal from New Mexico to the Eastern Seaboard. The nationally-averaged summer temperature was the second warmest on record, nearly identical to the summer of 1936 and highlighted by Oklahoma having an average summer

temperature of 30.5°C, marking the warmest three-month period for any state on record. The average autumn (September–November) temperature for the contiguous US was 0.7°C above average, ranking as the 16th warmest for the United States.

(ii) Precipitation

Precipitation for the contiguous US in 2011 was near normal, as the total was only 4.6 mm below the long-term average of 740 mm. The year was characterized by wetter-than-average conditions across the Ohio Valley and Northeast and drier-than-average conditions across the southern tier of the country. At the state level, it was a record-wet year for Connecticut, Indiana, Kentucky, New Jersey, New York, Ohio, and Pennsylvania. In contrast, Texas had its second driest year on record, at 54% of normal (Fig. 7.6b). The year began with about 18% of the country in moderate to extreme drought (based on the US Drought Monitor), mainly stretching from the Southwest through the Central Plains and into the Southeast.

It was the 20th driest winter (December–February) for the contiguous US since national records began in 1895. Consistent with the moderate-to-strong La Niña, most of the southern half of the nation was drier than average, while the Northern Plains were wetter than average. At the end of the 2010/11 winter, much-above-average snowpack was observed for most of the western mountains, in excess of 180% of normal across the Cascades, Sierra Nevadas, the Great Basin, and the Northern and Central Rockies. Below-normal snowpack was observed across much of the Southern Rockies of Arizona, New Mexico, and southern Colorado. Some areas of New Mexico had end-of-season snowpack totals below their 25th percentile. The winter average snow cover extent for the contiguous US ranked as the fifth largest in the 1966–2011 period of record.

The spring (March–May) precipitation across the United States varied greatly with 10 states record wet across the Northwest, Ohio Valley, and Northeast, while an additional 11 states had spring precipitation totals ranking among their ten wettest. However, the southern US continued to be drier than average during spring.

Summer (June–August) 2011 was the 17th driest for the US, with above-average precipitation across the Northeast, Northern Plains, and California. The southern United States continued to be dry as Texas had its driest summer on record, with just 62.0 mm of precipitation, compared with the previous driest summer in 1956 of 88.4 mm. The dry conditions, combined with the record heat, caused Texas to experience record potential evapotranspiration (natural water demand). Several climate divisions in Texas, New Mexico, Oklahoma, and Louisiana, as well as the Rio Grande and Texas Gulf Coast river basins, had record low values for the Palmer Hydrological Drought Index in the 117-year record.

Autumn precipitation was near average for the contiguous US. Parts of the Northeast and Ohio Valley had above-average precipitation, with Ohio and Pennsylvania being record wet. A significant portion of the seasonal precipitation came from Hurricane Irene and the remnants of Tropical Storm Lee. Many of the states west of the Mississippi River were near

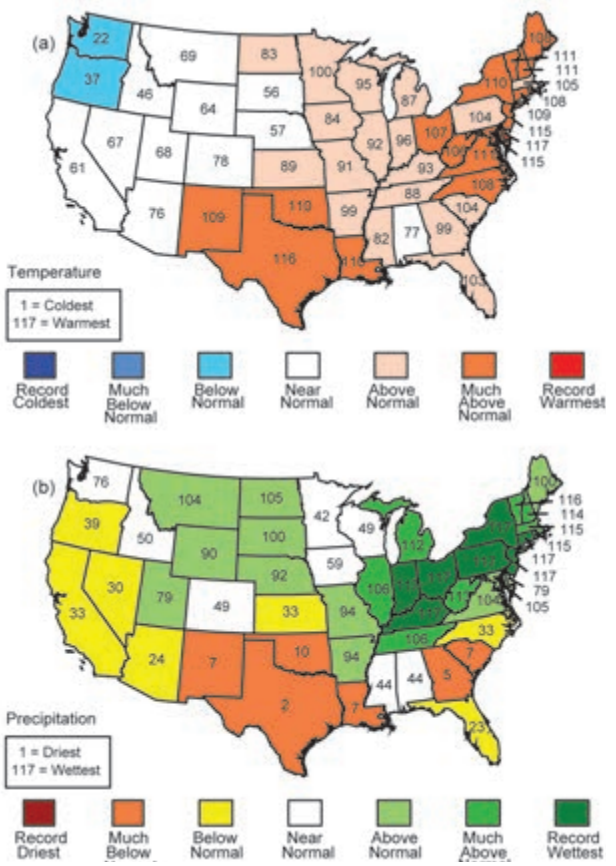

Fig. 7.6. Statewide ranks of annual 2011 (a) temperature and (b) precipitation. A rank of 117 represents the warmest/wettest year since 1895. Much-above-normal temperature/precipitation is defined as occurring in the top 10% of recorded years. Above-normal temperature/precipitation is defined as occurring in the warmest/wettest third of recorded years. Much-below-normal temperature/precipitation is likewise the bottom 10% of coolest/driest years since 1895, and below normal is defined as the coolest/driest third of the distribution. (Source: NOAA/NCDC)

average to drier than average. Minnesota had its third driest autumn on record.

(iii) Notable events

The US tornado season of 2011 was one of the most destructive and deadly on record. During the year, seven individual tornado and severe weather outbreaks caused damage exceeding $1 billion (US dollars), with total damage exceeding $28 billion (US dollars). This represents the most damage from severe weather in a single year since record keeping began in 1980. The 2011 confirmed tornado count stood at 1676, with 33 tornado reports still pending for December. This places 2011 as the second most active year on record for number of tornadoes since the modern record began in 1950.

The most active tornado period of the year was the spring (March–May), with 1150 confirmed tornadoes across the country, the most on record for any three-month period. The most active month was April, when 758 tornadoes were confirmed. This is the most on record for any month, surpassing the 550 reported in May 2003, and was driven by the two largest tornado outbreaks on record during 14–16 April and 25–28 April. These outbreaks both surpassed the April 1974 Super Outbreak for the most tornadoes during a single outbreak. The 199 tornadoes on 27 April was the most for any single day on record and the 316 fatalities on the same day was the most in the modern period of record for a 24-hour period. The 22 May Joplin, Missouri, tornado caused damages estimated at $3 billion (US dollars) and led to 158 fatalities, surpassing the previous records for both damages and fatalities from a single tornado in the modern tornado record.

During the late spring and early summer, historic flooding impacted much of the central United States. An above-average snowpack across the Northern Rockies, Northern Plains, and Ohio Valley combined with an anomalously wet spring caused significant runoff into the rivers. Some of the worst flooding occurred along the Mississippi, Ohio, Missouri, Souris, and James Rivers. The high water levels put significant stress on the levee systems along these rivers, and several levees were deliberately breached to flood farm lands and protect cities. Record historical crests were set along the Missouri and Mississippi Rivers, surpassing the floods of the 1920s and 1930s. Total damages approached $5 billion (US dollars).

During 2011, approximately 74 500 fires burned over 3.5 million hectares across the US. The southern US had the third most active wildfire year with respect to acres burned since records began 2000. Over 1.5 million hectares burned across Texas, the most of any state and 43% of the national total. The 2011 damages exceeded $1 billion (US dollars).

3) Mexico—R. Lobato-Sánchez, R. Pascual-Ramírez, and A. Albanil-Encarnación

After a very wet rainy season in 2010, Mexico experienced its second warmest year since 1971 and thirteenth driest year since 1941. According to preliminary data from the National Meteorological Service of Mexico, the nationally-averaged annual mean temperature was 21.8°C, 1.1°C above the normal temperature. Total precipitation was below average, at 89% of normal.

(i) Temperature

The national average temperature for 2011 was 21.8°C, (1.1°C above the 1971–2000 normal) and ranked second only to 2006 as the warmest year since 1971 (Fig. 7.7). The annual average temperature has been above normal since 1993. In 2011, the annual mean temperature was between 1.0°C and 1.3°C above normal for much of the country. However, some states such as Baja California and the central states of Michoacan, Mexico State, Morelos, Tlaxcala, and Puebla were cooler than normal, while Sonora, Morelos, and Yucatan were near normal (Fig. 7.8a).

Daily mean temperatures for 2011 are shown in Fig. 7.9. Through the year, the average temperature was influenced by three events. The first was an early February winter storm in the northwest that impacted the average national temperature, which dropped nearly two standard deviations below the long-term average. Second, a persistent climatic pattern led to the mean temperature during spring and summer being warmer than average, marking values over the

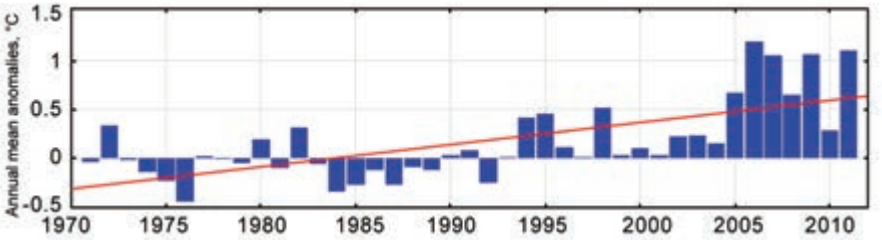

Fig. 7.7. Annual mean temperature anomalies (°C) for Mexico for the period 1971–2011. The red line represents the trend. (Source: Meteorological Service of Mexico)

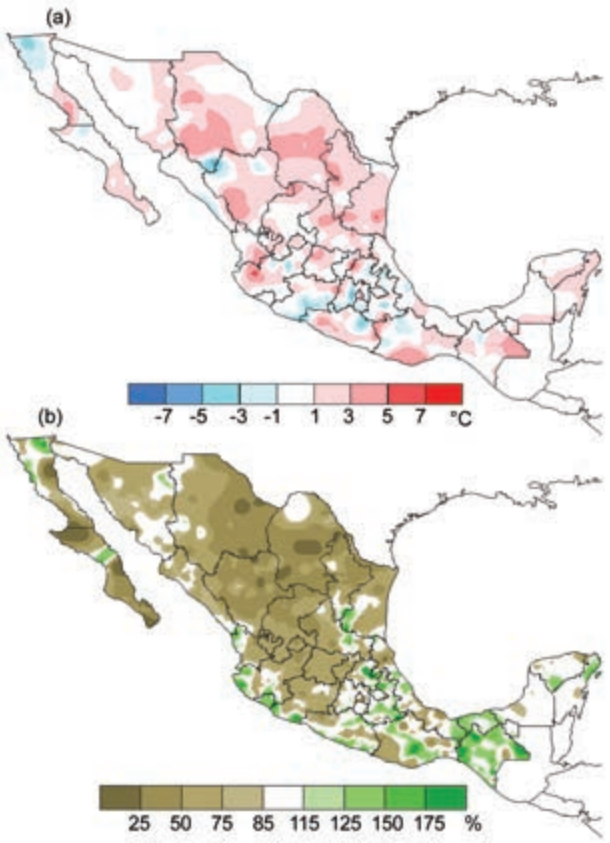

Fig. 7.8. (a) 2011 annual mean temperature anomalies (°C) for Mexico (based on 1971–2010 mean) and (b) 2011 annual precipitation anomalies (% of 1941–2010 mean). (Source: National Meteorological Service of México)

threshold of two standard deviations. Finally, in late November, a cold front caused the average national temperature to drop below the threshold of two standard deviations.

January was the coldest month of the year with 15.9°C (0.6°C below normal,) while the period October–December registered a mean of 18.9°C that was ranked as normal. June was the warmest month of 2011 averaging 25.9°C (2.9°C above normal). Through the rainy season (July–September), the mean temperature was 25.5°C (2.4°C above normal). The

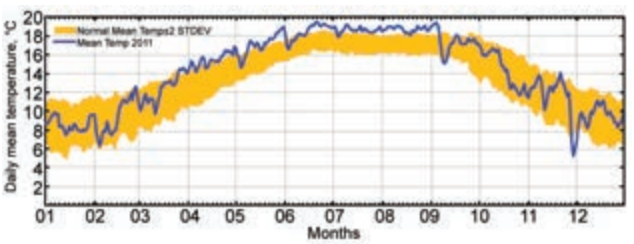

Fig. 7.9. Daily mean temperature in 2011 (solid blue). Shaded area represents the normal threshold of ±2 standard deviations derived from 1971–2000. (Source: National Meteorological Service of Mexico)

states of Coahuila, Nuevo León, and Zacatecas each had the warmest year over the last 41 years. Temperatures in Chihuahua, Durango, Aguascalientes, Distrito Federal, Tlaxcala, and Campeche ranked as second warmest. Guanajuato, Hidalgo, Quintana Roo, and Tamaulipas each ranked among their top five warmest.

(ii) Precipitation

Nationally, the year 2011 ranked as the thirteenth driest for Mexico since 1941, averaging 697.2 mm, ~90% of normal. Rainfall was much below normal during nine months. Only June, July, and November had precipitation near or above normal. The rainfall spatial distribution showed marked differences between the southern and northern regions of the country (Fig. 7.8b). The wettest zones with annual rainfall over 1500 mm were located southward of 22°N covering the zones of Nayarit, Colima, Guerrero, Veracruz, Tabasco, and Chiapas; Colima, Chiapas, and Quintana Roo were the wettest states across the country. In contrast, total rainfall of less than 50% of normal was observed from central zones to northward regions. Below-normal rainfall was reported in Coahuila, Chihuahua, Durango, and Baja California, all averaging less than 25% of normal. Durango and Aguascalientes were classified as the driest, with Zacatecas and Guanajuato second driest, Baja California Sur and Coahuila the third driest, and Nuevo Leon and Chihuahua reached the fourth driest year.

(iii) Notable events

The year 2011 set a new record with the largest area (956 405 hectares) burned by forest fires, exceeding the previous record of 1998 with 843 633 hectares; Coahuila was the federal state with the largest area burned, 44% of the total.

The long-term drought during 2011 was due to a significant reduction in rainfall beginning in late autumn 2010. In June, the drought-affected region expanded to 85% of the country; this decreased progressively with the onset of the rainy season, reaching 55% in September, but increased again in October to 61%. By late December, the drought impacts decreased slightly in the north, mainly due to the winter storms described in the previous section; however, it had expanded towards the central region. The area that experienced moderate to exceptional drought covered 54.6% of the nation, according with the North American Drought Monitor definition, with 9.7 % in the highest category of exceptional drought.

As of the date of this publication, the impacts of the drought on agriculture, livestock, and human populations have not been completely calculated. Most of the dams located in the northern region had their lowest levels following a poor recharge in the summer 2011. The bean crop dropped by almost half due to the late onset of the rainy season, delaying the sowing. Only 53.4% of croplands were planted in the main bean-producing states of Chihuahua, Durango, Zacatecas, and San Luis Potosí; in Sinaloa, less than 50% of agricultural lands were cultivated during the fall–winter 2011/12 season and pastures were not sufficient to feed the livestock. The federal government implemented national and local programs to support the population in order to mitigate the drought impacts, including water delivery for domestic use and temporary employment programs to reinvigorate local economies.

c. *Central America and the Caribbean*

1) Central America—J. A. Amador, H. G. Hidalgo, E. J. Alfaro, B. Calderón, N. P. Mora, and I. L. Rivera

For this region, 11 stations were analyzed from 6 countries. The stations located on the Caribbean side are: Phillip Goldson International Airport (MZBZ), Belize; Puerto Barrios, Guatemala; Puerto Lempira, Honduras; Puerto Cabezas, Bluefields, Nicaragua; and Puerto Limón, Costa Rica. The following stations are located on the Pacific side: Tocumen International Airport (MPTO) and David, Panamá; Liberia, Costa Rica; Choluteca, Honduras; and San José, Guatemala.

(i) Temperatures

On the Caribbean side, the mean temperature for the 2001–10 decade was warmer than the 1971–2000 average, with 0.5°C above average at MZBZ, Puerto Lempira, and Puerto Cabezas, and Bluefields. Meanwhile, near-average conditions were present at Puerto Barrios and Puerto Limón. The 2011 mean temperature was near average when compared to the 2001–10 decade, with the exception of Puerto Barrios and Puerto Lempira. During the last decade, the Pacific southernmost stations at MPTO and David, experienced above-average temperatures. In contrast, Liberia had cooler-than-average temperatures, while the northernmost stations of Choluteca and San José had near-average temperatures. A striking feature of 2011 was the higher frequency of near mean temperature conditions and smaller frequency of high mean temperature values in all the Pacific side stations (shown as green line distributions in Fig. 7.10). Since many stations have a large amount of missing data in their daily minimum and maximum temperatures, these two variables were analyzed regionally by taking an average of the five stations on the Pacific slope and the six stations on the Caribbean side. Both minimum and maximum temperatures for the last decade and 2011 were warmer than the 1971–2000 average in the Caribbean and Pacific basins.

(ii) Precipitation

Across Central America's Pacific side, the stations experienced a near-average rainy season (May–November), with the exception of Choluteca and David, which had a significant early start when compared to the 1971–2000 average. However, when compared to the 2001–10 decade, most stations had a normal start to the rainy season, with the exception of David, which had a late start. Consistent with the La Niña influence and the impact of warmer-than-normal Caribbean sea surface temperatures, the end of the rainy season was later than normal across all stations. With respect to the previous decade, 2011 had a late ending in all stations (but significant in only two stations) with the exception of Choluteca, which showed normal conditions.

(iii) Notable events

The year 2011 was slightly below average in terms of tropical storm activity in the Caribbean basin (6°N–24°N, 92°W–68°W), which is unusual considering the development of La Niña and much weaker-than-average 900 hPa winds (inserted arrows in Fig. 7.10) during the period of the prevalence of the Caribbean low-level jet (a characteristic of La Niña events in the region and a condition favorable for tropical cyclone formation; Amador et al. 2006). In the Caribbean basin, Tropical Storm Harvey (19–22 August) and Hurricane Irene (21–28 August), and in the Pacific, Tropical Storm Dora (18–24 July), impacted Central America in different ways, but no human casualties were reported from any of those systems.

The significant 2011 storms that wreaked havoc across Central America were Tropical Depression 12-E (12–13 October) and Hurricane Rina (23–28 October). Rina triggered landslides and floods due to heavy rains in Belize, Guatemala, Honduras, and Nicaragua. A total of 46 fatalities, mostly from Honduras and Nicaragua, were attributed to Rina. Despite the relatively high storm activity in the eastern Pacific, the major regional impact to economic and social welfare was not caused by a hurricane, but by Tropical Depression 12-E (approximate trajectory in red dots in Fig. 7.10). This storm caused significant

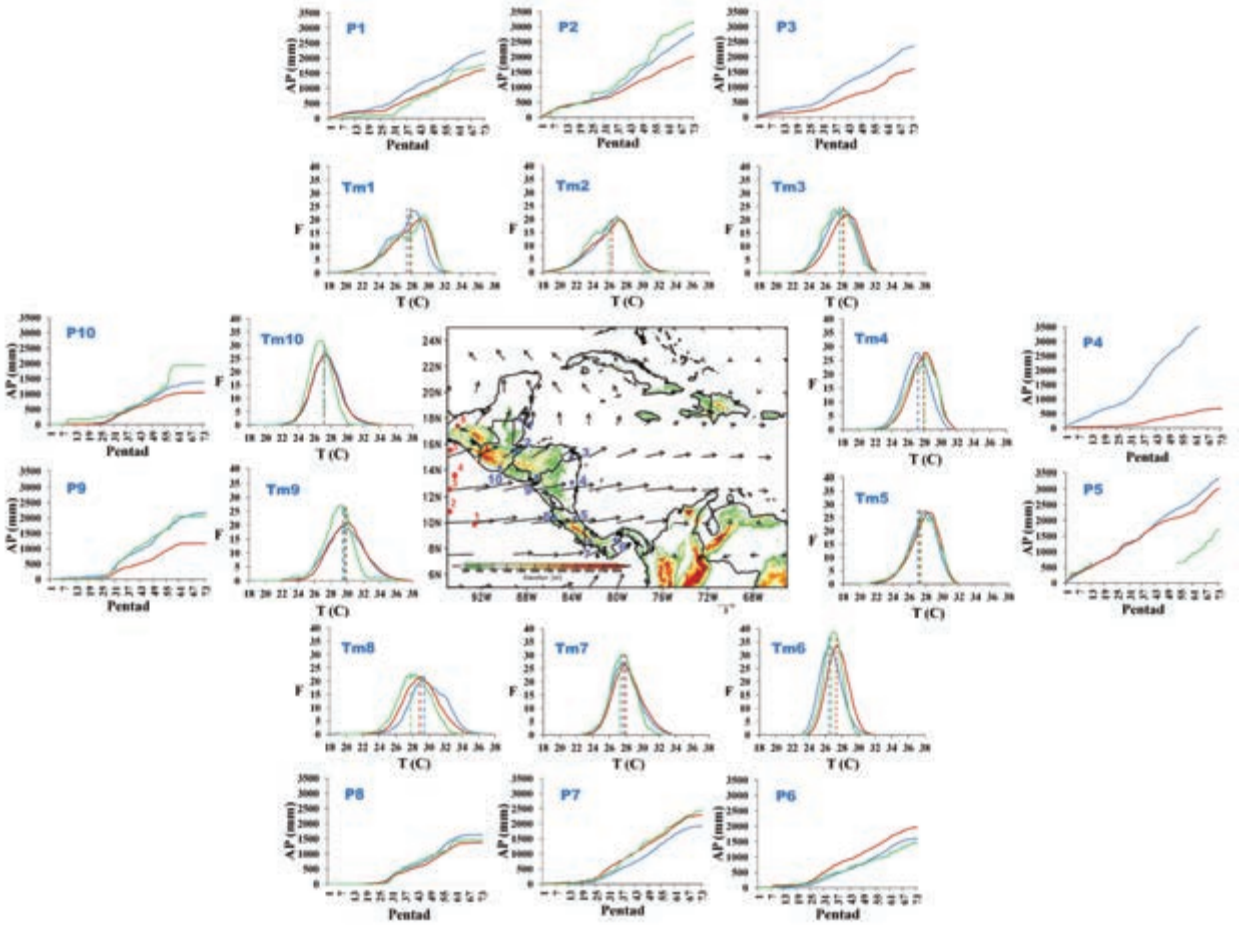

Fig. 7.10. Mean surface temperature frequency (Tm) and accumulated pentad precipitation (P) time series shown for the 10 stations (blue dots depict station location) in Central America: (1) Phillip Goldson International Airport, Belize; (2) Puerto Barrios, Guatemala; (3) Puerto Lempira, Honduras; (4) Puerto Cabezas and Bluefields (showed at their mean geographical position; see text for explanation), Nicaragua; (5) Puerto Limon, Costa Rica; (6) Tocumen International Airport, Panama; (7) David, Panama; (8) Liberia, Costa Rica; (9) Choluteca, Honduras; and (10) San Jose, Guatemala. Blue line represents the 1971–2000 average (base period), red the 2001–10 decade, and green 2011. Note that stations (3) and (4) do not show 2011 precipitation due to a large number of missing data, and station (5) only shows available data for the beginning and ending of the rainy season. The start and end of the rainy season is calculated as follows: the precipitation pentad data were analyzed starting from the beginning of the year. If in any particular pentad at time "t" the precipitation was greater or equal to 25 mm, and the precipitation of day t+1 was also greater or equal to 25 mm, and the precipitation of t+2 was greater than zero, it was considered that the rainy season started at time t. A similar procedure was used for computing the end of the rainy season, with the exception that the procedure was applied from the end of the year backwards. Wind anomalies at 925 hPa, based on 1958–99 for July. The approximate track for Tropical Depression 12-E is shown for locations 1 to 6 (red dots) at 7 October 00Z, 7 October 12Z, 11 October 12Z, 12 October 00Z, 12 October 12Z, and 13 October 00Z, respectively. (Source: NOAA/NCDC)

economic losses in Guatemala, El Salvador, Honduras, Nicaragua, and Costa Rica ($397, $902, $204, $445, and $0.1 in US million dollars, respectively) with a total of 117 human casualties. A lesson learned from Tropical Depression 12-E is that the relative position and low system motion of a tropical depression with respect to highly vulnerable areas, such as those in Central America, are as important as tropical storm intensity.

2) The Caribbean—M. A. Taylor, T. Stephenson, A. Trotman, J. Spence, O. Martínez-Sánchez, G. Votaw, I. González-García, R. Pérez-Suárez, B. Lapinel-Pedroso, A. León-Lee, D. Boudet-Rouco, and N. González-Rodríguez

The climate conditions across the Caribbean during 2011 were largely impacted by the end of the La Niña event in May, the onset of another La Niña in October, and very warm Caribbean sea surface temperatures (SSTs) in the Main Development Region

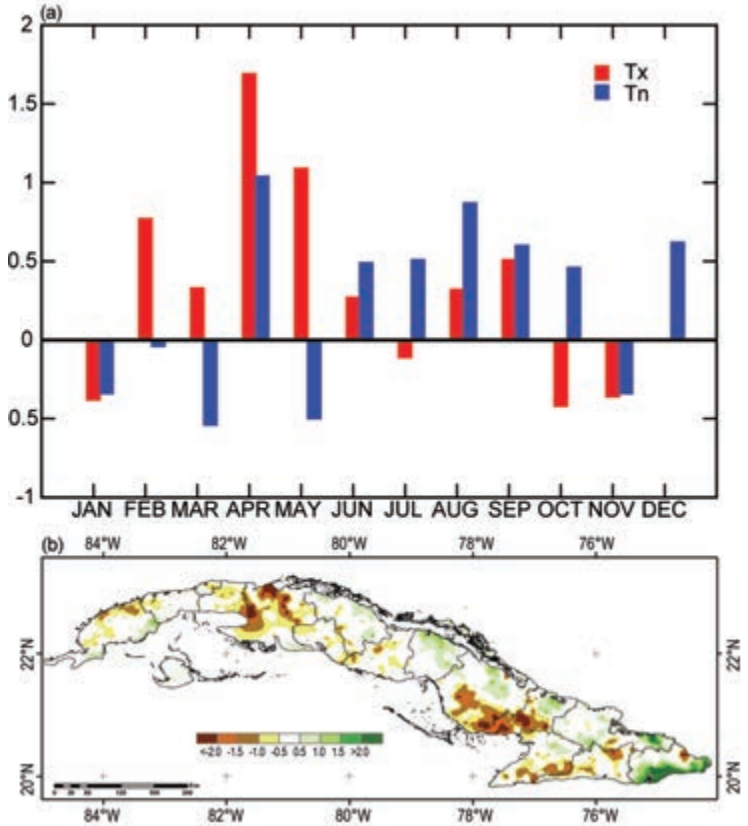

Fig. 7.11. (a) 2011 monthly mean maximum (Tx) and minimum (Tn) temperature anomalies (°C) for Cuba; (b) Annual precipitation anomalies represented as Standardized Precipitation Index (unitless; based on 1971–2000 base period). (Source: Institute of Meteorology of Cuba)

(MDR) for hurricanes (10°N–25°N, 80°W–20°W) in June and July.

(i) Temperatures

Parts of the eastern Caribbean experienced below-average temperatures for the latter half of the year. Antigua recorded its third coolest July and second coolest August and experienced slightly below-average temperatures in September and December. In Dominica, the 2011 mean temperature at Melville Hall Airport (TDPD) was 26.7°C, which was the lowest value in the last 30 years.

In Puerto Rico, the 2011 average maximum temperature at the Luis Muñoz Marin International Airport (TJSJ) in San Juan was 0.6°C cooler than the 1981–2010 average of 30.4°C. The mean temperature at TJSJ was below average for 39% of the year and above average during 34% of the year. The 2011 average minimum temperature at TJSJ was 23.6°C, which is 0.5°C cooler than the 1981–2010 average. Across the US Virgin Islands, the mean annual temperature at Henry E. Rohlsen Airport (TISX) in Saint Croix and Cyril E. King Airport (TIST) in Saint Thomas was 0.7°C and 0.6°C below average, respectively.

In Cuba, monthly minimum and maximum temperatures were near average during 2011 (Fig. 7.11a). However, April and May were significantly warmer than average, with maximum temperature anomalies above 1.0°C across all of Cuba. April 2011 was the third warmest April of the last 30 years in Cuba. There were significant positive anomalies of the effective temperature throughout the country, and positive anomalies (as high as 1.4°C) across the western and central regions. In addition, the percentage of days with maximum temperatures above the 90th percentile was the highest since April 1961.

For Jamaica, extreme temperatures were recorded by several automatic weather stations across the island. The highest maximum air temperature recorded was 37.3°C, at Barton Isles, St. Elizabeth, in July, while an extreme minimum air temperature of 13.8°C was recorded at Bunkers Hills, Trelawny, in February.

(ii) Precipitation

Precipitation patterns during the Caribbean's dry season (December–April) were impacted by the 2010/11 La Niña event. The impact held true to noted

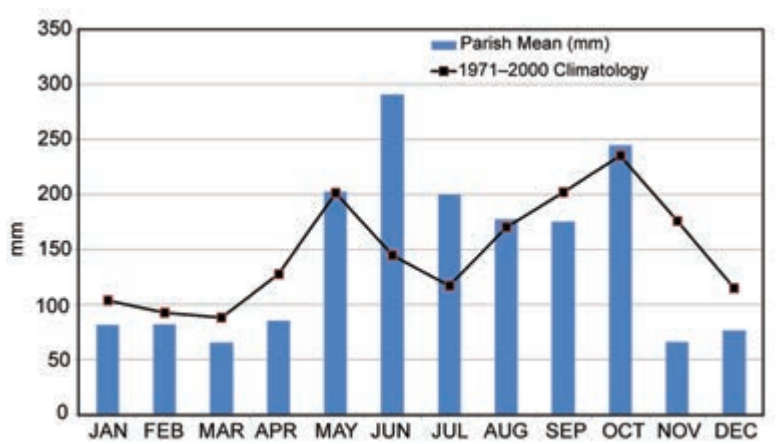

Fig. 7.12. 2011 mean monthly rainfall (mm) for Jamaica (blue bars) and long-term average 1971–2000.

tendencies (Stephenson et al. 2007), with the Caribbean being wetter than average in the south and east, but drier than average in the north and northwest.

In Jamaica, rainfall totals were 70–90% of normal during every month through April, with the largest deficit (67% of normal) occurring in April (Fig. 7.12). The Dominican Republic reported a similar deficit in rainfall for January–March (SERVIR 2011). In Cuba, 82% of the country experienced moderate to severe drought conditions during March–May, and in Puerto Rico, only 85% of the normal precipitation fell through April. St Croix's TISX recorded its driest January on record.

In contrast, the southern and eastern Caribbean experienced much-above-average rainfall. The Barbados Meteorological Service references a "very wet" dry season with cumulative rainfall of 507.2 mm during January–May, almost twice the 1961–90 average. Rainfall in April was 143.3 mm, or twice the monthly mean, and through May there were approximately five more rain days (≥ 1 mm) per month than the long-term average. The wet "dry season" contributed to an annual rainfall of 1681 mm, the fifth highest since 1942. Similarly, dry season rainfall at both Canefield Airport (TDCF) and Melville Hall Airport (TDPD) in Dominica was 150% of the 1982–2010 average, with TDCF recording 2458.5 mm—the highest since 1982. Monthly rainfall at the E.T. Joshua Airport (TVSV) in St. Vincent and the Grenadines for January–April exceeded each month's long-term average (1979–2011 base period), with April rainfall (236.7 mm) being more than twice the average of 92.8 mm. In St. Lucia, April was the wettest month for the year, with 407.9 mm, which represented the highest April amount recorded at Hewanorra Airport (TLPL) since 1973. An abnormally wet "dry season" was also noted for Grenada (above average for January–April) and for Trinidad (see special issue of *CAMI Monthly Bulletin*, 2012, Vol. 5, No. 1).

By June, with the decline of La Niña and the onset of very warm Caribbean SSTs, most islands experienced average or above-average rainfall, with a few records set between June and August due to the passage of a series of tropical systems, including Tropical Storms Emily and Irene. From as early as April, SSTs in the MDR were 0.5°C above average, representing the 14th warmest April SSTs in the last 100 years. The warm surface temperatures persisted through July, with June recording the third largest anomaly since 1950. Rainfall totals in June and July were above average, particularly across the Greater Antilles, significantly offsetting the deficit previously recorded for these northern territories, and, notably occurring during the period referred to as the midsummer drought (July–August). For Jamaica, the July rainfall total (200 mm) was the seventh highest since records began in 1881 (Fig. 7.12). In Antigua, the July and August rainfall were the second and ninth highest, respectively for those months, since national records began in 1928. St. Croix's TISX had its second wettest June and third wettest July. Martinique had its seventh wettest July and second wettest August on record. In Puerto Rico, a rainfall surplus of 914.4 mm from late May through September was reported for the San Juan Metro Area with 141% of the normal precipitation falling across all Puerto Rico. In fact, summer 2011 was the wettest summer on record at TJSJ with a rainfall total of 1098 mm between June and August. For May–November, most islands reported near-normal rainfall or slightly above-normal activity. The Caribbean Drought and Precipitation Monitoring Network (CIMH 2012) noted that August–October rainfall in the eastern Caribbean islands of Trinidad, Barbados, and St. Lucia was normal, while conditions for Grenada, St. Vincent, Dominica, Antigua, and St. Kitts ranged from moderately to abnormally wet. St. Thomas's TIST had its wettest August and driest October on record. In the north, Jamaica's rainfall was near aver-

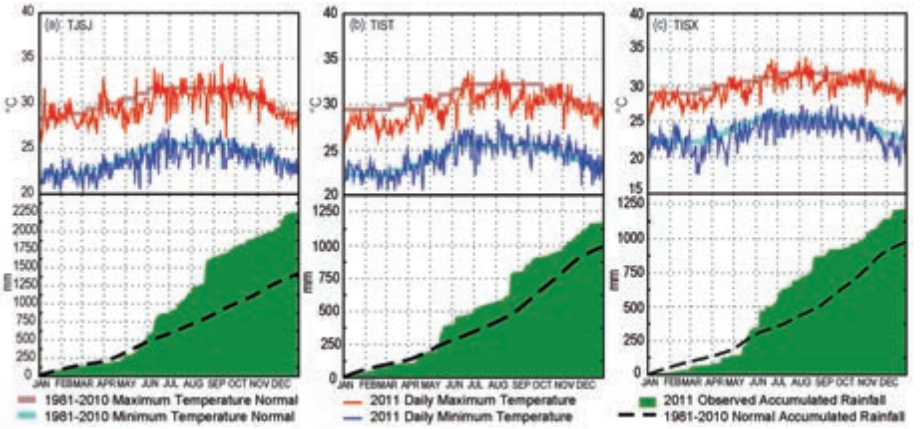

Fig. 7.13. top: 2011 observed daily maximum temperature (°C, red), 1981–2010 daily maximum temperature normal (°C, brown), 2011 observed daily minimum temperature (°C, blue), 1981–2010 daily minimum temperature normal (°C, light blue). bottom: 2011 accumulated rainfall (mm) and 1981–2010 mean accumulated rainfall (mm) for (a) TJSJ, (b) TIST, and (c) TISX. (Source: NOAA/NWS)

age. By December, with the onset of the Caribbean dry season, the La Niña pattern of a dry northwet south appeared to reemerge. Whereas Barbados, Trinidad, and St. Kitts were wetter than average, Jamaica was drier than average.

Overall, in Puerto Rico, 2011 ranked as the second wettest year in nearly 113 years of record keeping in the San Juan Metro Area. An impressive rainfall total of 2239 mm was reported at TJSJ, which is 807.7 mm above average (Fig. 7.13a). This total was 34.3 mm less than 2010, the wettest year on record. According to the Cooperative Weather Observer Data, 2011 was a wet year across the entire forecast area, with 126% of the normal precipitation falling across all of Puerto Rico and 121% of normal falling across the US Virgin Islands (USVI). 2011 ranked as the ninth wettest year on record at TIST, as well as TISX, with rainfall totals of 1172 mm and 1212 mm, respectively (Figs. 7.13b,c).

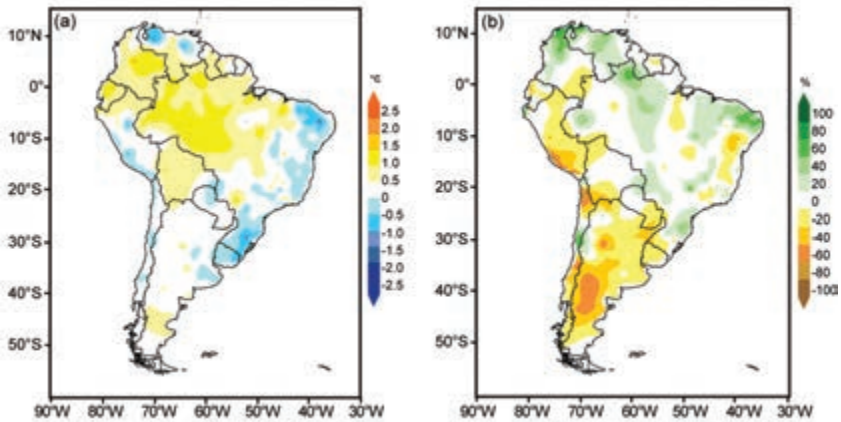

Fig. 7.14. (a) 2011 annual mean temperature anomalies (°C) for South America (1971–2000 base period), and (b) 2011 annual precipitation anomalies (%) (1971–2000 base period). (Sources: National Meteorological Services of Argentina, Brazil, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Suriname, Uruguay, and Venezuela. The data was compiled and processed by CIIFEN, 2011)

For Cuba, the annual average rainfall for 2011 was near average. Based on the Standardized Precipitation Index (SPI), 20% of the country had above-average rainfall accumulation during 2011, with 5% of the country falling in the moderate to extreme category, while 33% of the country reflected deficit, with 15% in the moderate to extreme category (Fig. 7.11b).

(iii) Notable events

Significant 2011 storms for Caribbean islands include Tropical Storm Emily and Hurricane Irene. Although Emily was a fairly disorganized storm as it tracked into the northeastern Caribbean, it generated strong thunderstorms and gusty winds along its path. Within a 72-hour period on 31 July–3 August, more than 225 mm of rainfall was recorded at St. Vincent and Grenadine's TVSV. On 2–3 August, Emily tracked south of Puerto Rico and the USVI, leaving rainfall accumulations between 102 mm and 152 mm, with locally higher amounts of up to 254 mm. The higher rainfall accumulations were observed across the eastern half and portions of southwest Puerto Rico. After tracking over Hispaniola and exiting the northeastern Caribbean on 6 August, its remnants regenerated into a tropical storm, before dissipating the next day. In Puerto Rico, the storm caused at least $5 million (US dollars) in infrastructure damage. Hispaniola was also impacted, where five fatalities were reported in addition to nearly 8000 homes being damaged.

Also notable was Hurricane Irene, which was the first hurricane of the season. Irene originated from a well-defined Atlantic tropical wave east of the Lesser Antilles. On 21 August, Irene made landfall in Puerto Rico at Category 1 hurricane strength, resulting in severe flooding, significant property damage, and one fatality. The 72-hour maximum precipitation totals ranged from 381 mm to 559 mm. With rainfall from this storm, August 2011 ended as the wettest August on record as well as the wettest month ever across the San Juan Area, with a rainfall total of 471.4 mm. Irene tracked just north of Hispaniola as an intensifying cyclone, causing heavy rainfall and strong winds and killing seven people. After crossing the Turks and Caicos Islands, the hurricane quickly strengthened into a Category 3 major hurricane while passing through The Bahamas. It left behind a trail of extensive structural damage in its wake, primarily on Cat, Mayaguana, Acklins, and Crooked Islands. Government reports noted that upwards of 90% of all homes and structures on the islands were damaged. Thereafter, Irene curved north and impacted the United States. Total Caribbean economic losses were estimated at nearly $1.5 billion (US dollars), with combined insured losses listed around $1 billion (US dollars), primarily due to damage in the Bahamas.

d. South America

The 2011 annual mean temperature was near normal to above normal in northern South America, the tropical Andes, and western Amazonia. Peru, Chile, and the Atlantic coast of South America were characterized by near-normal to below-normal temperatures (Fig. 7.14a). The annual total precipitation was above normal in northern South America and central Amazonia, but generally below normal in western South America, Argentina, Paraguay, and Uruguay (Fig. 7.14b).

Climate conditions across the region during 2011 were influenced by a La Niña event during the first few months of the year, and the reemergence of La Niña conditions during the latter part of the year. Typically, La Niña produces above-average precipitation across northern South America, and below-average precipitation across southeastern South America.

1) Northern South America and the tropical Andes—R. Martínez-Güingla, J. Arévalo, G. Carrasco, E. Jaimes, and G. León

(i) Temperatures

The La Niña influence over the northern parts of South America was evident in the region's temperature. Temperatures during January–March were predominantly cooler than normal across Colombia, Ecuador, and Peru, with temperature anomalies ranging from 0.5°C to 2°C below the 1971–2000 average. Coinciding with the decline of La Niña in June, temperatures across the area were warmer than average. In Ecuador, temperature anomalies were between 0.5°C and 1.5°C above average during July–September. Although minimum temperatures across Peru were near normal during April–June, maximum temperatures were 3°C above average. With the reemergence of La Niña in October, temperatures across northern South America were cooler than normal during the final months of the year.

(ii) Precipitation

In Venezuela, above-normal precipitation was observed during most of 2011, mainly due to the influence of La Niña. The largest precipitation anomaly (166% of normal) was observed during January–March. July–September was the only time during the year that recorded below-average precipitation, at 94% of normal. Overall, 2011 was among the top five wettest years for several stations across the country.

Colombia experienced above-average precipitation throughout the year, attributed to La Niña conditions during the first and last few months of the year. North and central regions of Colombia were affected by heavy rainfall during January–March, with anomalies between 150% and 200% of normal. In December, precipitation anomalies ranging from 600% to 900% of normal were observed over northern Colombia. Overall, the heavy precipitation observed across Colombia throughout the year caused more than 250 deaths and affected two million people.

The coastal region in Ecuador reported anomalies that were 0–80% of normal during January–March. During April–June, specifically in April, 150–250% of normal rainfall was observed across the country. July–September was characterized by above-average precipitation over the highlands and the southern coast, with anomalies ranging between 150% and 800% of normal (El Oro Province). The highest monthly precipitation anomaly of 840% of normal was registered in Zaruma (located in southern Ecuador) in July. During October–December, precipitation deficits were observed across the coastal region, with positive anomalies in the Amazonia area.

In Bolivia, above-average precipitation was observed in the eastern Llanos, Altiplano, and valleys during January–March. In January, a maximum daily precipitation of 194 mm was registered in eastern Llanos, where the monthly normal is 162 mm.

In Peru, precipitation anomalies over the northern region during January–March were 0–40% of normal, while above-average precipitation was observed across the central and southern regions. During April–June, precipitation anomalies over the northern Amazon jungle and the northern and central highlands reached 400% of normal. During October–December, northern and central parts of the country experienced above-average precipitation, while the south had below-average precipitation.

(iii) Notable events

The Libertador Municipality in the Capital District of Venezuela—one of the most densely populated areas in the country—was affected by heavy precipitation that prompted flooding and triggered landslides, leaving over 8900 families homeless. The Orinoco River, the country's largest river, had an above-normal flow level during most of the year. In August, the Apure River flooded, affecting many rural populations.

In Colombia, more than 350 windstorms occurred between June and September in different areas of the country, affecting thousands of families. Strong hailstorms were registered in Bogota, Santander,

and Cundinamarca in April, July, and October, respectively.

Between January and February, in Cuzco, Peru, a precipitation anomaly over 400% of normal and stream flow of Paucartambo River of 400% were registered. This isolated main archeological sites, resulting in economic losses in the tourism sector.

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

(i) Temperatures

In January, all of tropical South America experienced warmer than average conditions, about 1°C above the 1961–90 average, while near-average temperatures were observed in February and March. In April, warm conditions continued over central and southern Brazil, western Bolivia, and Paraguay, and continued in May and June in northwestern Amazonia and Bolivia. During July–August, warmer-than-average conditions persisted across most of the region, with anomalies around +2°C in southeastern Brazil.

However, some regions experienced cooler-than-average conditions, nearly 1°C below average, during June–August, due to various cold waves that impacted the area. At the beginning of June, a freezing episode in the southern Andes of Peru impacted 13 400 people and 4500 head of cattle. At the end of June and beginning of July, cold waves brought cooler-than-average temperatures to the region. Minimum temperatures between 2.8°C and 5.3°C were observed in São Paulo, where the mean July minimum temperature is 11.7°C (1961–90 base period), and the minimum temperature dropped from 20.3°C to 12.6°C, between 1 and 4 July, in Vilhena (Southern Amazon). By mid-July, more than 6000 people and 41 000 head of cattle had been affected by temperatures as low as -26°C and 1.6 meters of snow in the Bolivian department of Potosi (southern Altiplano).

In August, five cold surges affected southeastern South America; the two most intense affected Vilhena and southern Brazil. Cold air surges continued during September–November. In the city of São Paulo, the maximum temperature dropped from 33.1°C to 17.9°C in two days. In December 2011, the lack of rainfall in south central Brazil contributed to warm conditions in the states of Mato Grosso and São Paulo, with temperatures up to 3°C above average.

(ii) Precipitation

During 2011, rainfall was slightly below average (50 mm below the 1961–90 average) across the 5°S–15°S latitude band in South America, as well as in southern Bolivia, southern Brazil, and Uruguay. Southern Bolivia, southern Brazil, and Uruguay were impacted by drought, which had begun in August 2010, affecting crops that resulted in nearly $60 million (US dollars) in losses. Meanwhile, rainfall was nearly 150 mm above average from Colombia to northeastern Brazil, eastern Bolivia, and northern Paraguay.

In January 2011, heavy rains, floods, and mudslides in the Oxapampa region in the central Andes of Peru affected more than 1100 people. In the highlands of the state of Rio de Janeiro, heavy rainfall during January caused the worst flooding and landslides in Brazil in decades. Between 11 and 13 January, nearly 1000 people died and 35 000 were left homeless (see Sidebar 7.1). In the city of São Paulo, January 2011 was the wettest since 1943, reaching 491.5 mm, almost twice the month's average.

In February, rainfall in southern Peru, Bolivia, Paraguay, and northern Argentina was about 200 mm above normal. Above-average rainfall (50 mm–200 mm) was observed across northeastern South America and Colombia.

In March, a reversal of rainfall patterns occurred, with below-average rainfall in Bolivia and Paraguay. Above-average rainfall persisted over northern South America and southeastern Brazil (about 150 mm above average). The January–March sequence resulted in deficit of rainfall (as much as 200 mm below average) in parts of western and southern Amazonia, just at the peak of the rainy season. In the Peruvian Amazon, however, the water level of the Amazonas River in Iquitos increased very rapidly after the 2010 drought episode, due to very wet local conditions.

In April, rainfall was 200–300 mm above average in Ecuador and most of western Colombia. In May, rainfall was up to 200 mm above average from northern South America to northeastern Brazil. In the state of Pernambuco, in northeastern Brazil, intense rainfall left 144 000 people homeless. In contrast, rainfall was below average from southern Colombia to southern Brazil.

During June–August, below-average rainfall was detected over northern Brazil, Venezuela, and eastern Colombia (200 mm below average). As a consequence, the level of the Rio Negro in Manaus registered a drop of about 1.24 m between 13 and 16 September, which is considered the largest reduction in a short time period since 1903 (according to the Serviço Geológico do Brasil). In contrast, intense rainfall continued in western Colombia and northeastern Brazil. Nine people were killed in Pernambuco and

SIDEBAR 7.1: THE 2011 INTENSE RAINFALL AND FLOODS IN RIO DE JANEIRO—J. A. MARENGO AND L. M. ALVES

During January 2011, heavy rainfall sparked flash flooding and mudslides across the highlands of the state of Rio de Janeiro in southeastern Brazil, devastating mountain towns. According to Brazilian official sources, the floods and landslides claimed the lives of 916 people and left 35 000 people homeless. This was one of the worst natural disasters in Brazil's history.

During the first half of January, rainfall in Brazil was primarily concentrated in a swath from the states of São Paulo, Minas Gerais, Goiás, and southeastward to Rio de Janeiro. While the 1961–90 average rainfall for January in that region is about 230 mm, the rainfall accumulated during January 2011 was approximately 460 mm. According to the Brazilian Meteorological agencies CPTEC INPE (http://www.cptec.inpe.br) and INMET (http://www.inmet.gov.br), the anomalous rainfall was caused by the South Atlantic convergence zone (SACZ), a typical summer time rainfall-producing mechanism that was fed by moisture transport coming from the Amazon region during that period and by a favorable signal of convection and precipitation by the Madden–Julian oscillation (MJO), that persisted until mid-January. The large-scale pattern was characterized by a weakening of La Niña in the equatorial Pacific Ocean, while over the South Atlantic Ocean, off the coast of southeastern Brazil, sea surface temperatures were 2°C above normal. Three episodes of SACZ were detected: 1–7 January, 11–17 January, and 18–21 January. The two earlier episodes produced intense low-level convergence over southeastern Brazil, intensified by plenty of moisture coming from the Amazon region. As a consequence, rainfall in the highlands of Rio de Janeiro during 1–7 January was about 86 mm–160 mm and about 300 mm in 11–17 January (Fig. SB7.1), well above the January average.

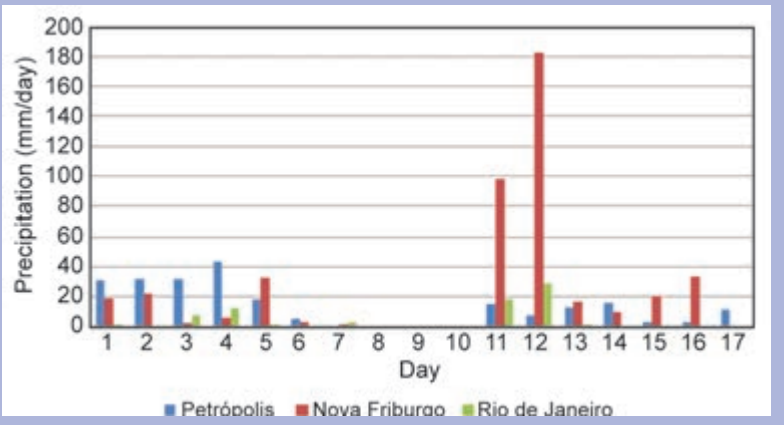

Fig. SB7.2. Daily precipitation (mm) during 1–17 January 2011 in Petrópolis (blue bar), Nova Friburgo (red bar), and Rio de Janeiro (green bar). Monthy January average (1961–90 base period): Nova Friburgo: 232.5 mm; Petrópolis: 201.5 mm; and Rio de Janeiro: 136.4 mm. (Source: INMET)

These conditions favored weeks of saturated soil, and together with the intense rainfall from 11 to 13 January, floods and mudslides were triggered. Numerous houses located in risk areas on the deforested slopes of the mountains were buried, killing hundreds of people. In one of the most affected cities, Nova Friburgo, rainfall on 11–12 January was 182.8 mm, 79% of the monthly average of 232.5 mm (Fig. SB7.2). According to the Civil Defense of the state of Rio de Janeiro, 428 people died in this city alone. Croplands were destroyed. Highways, roads, hospitals, and sewage systems all collapsed. The isolation of these cities and the risk of epidemics left the population and local governments in a permanent state of alert.

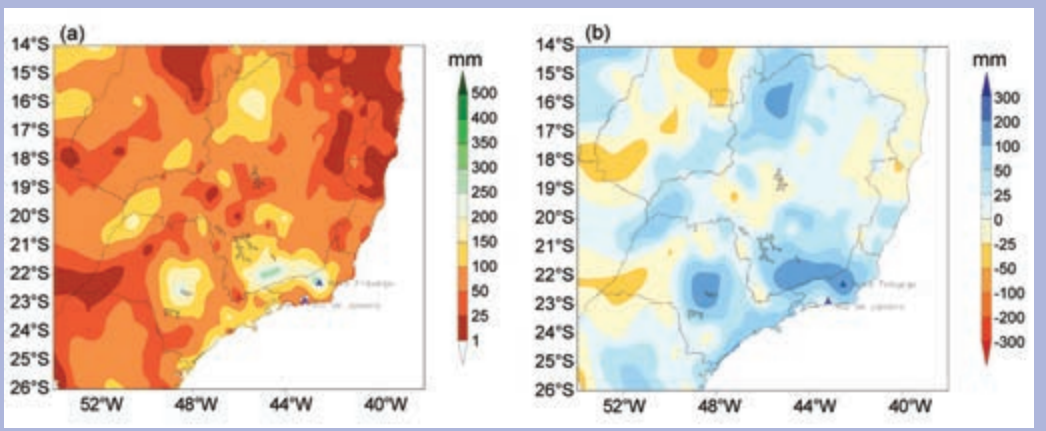

Fig. SB7.1. (a) Accumulated rainfall (mm) 11–17 January 2011 in the southeastern Brazil region and (b) rainfall anomalies (mm) for the same period from the 1961–90 base period. The cities of Rio de Janeiro and Nova Friburgo are marked on the map. (Source: CPTEC-INPE)

one in Paraiba, and more than 340 families lost their homes in mid-July. By the first week of August, the state of Parana in southern Brazil experienced heavy rainfall and storms, affecting more than 20 cities and 150 000 people. The Iguacu River reached a record flow of 12.5 million L s^{-1}.

In September, drier-than-average conditions persisted in western Amazonia (100 mm–200 mm below average). During the second week of September, intense rainfall in the state of Santa Catarina in southern Brazil left almost 15 000 people homeless, affected more than 900 000 people, and destroyed highways.

From November to December, floods and landslides affected hundreds of people and damaged roads and crop fields in the northern and central Andes of Peru. At the beginning of December 2011, heavy rainfall across northern Venezuela caused rivers to overflow, affecting almost 2000 people. On the other hand, most of tropical South America had below-average precipitation (as much as 200 mm below normal in Amazonia).

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

(i) Temperatures

Near- or above-average temperatures were observed over most of southern South America during 2011, with average anomalies up to +1.0°C (Fig. 7.14a). The greatest positive anomaly was observed in Patagonia (south of 40°S in Chile and Argentina).

During December 2010–February 2011 (austral summer), warmer-than-average temperatures (+0.5°C to +1.0°C) were observed in Argentina, Uruguay, and central Chile. This behavior was accompanied by positive deviations of the mean maximum and minimum temperatures and below-normal rainfall in the region, during La Niña. From December 2010 through the first days of January 2011, extremely high temperatures (at or above the 90th percentile) affected different regions of Argentina and southern Chile. Over eastern Uruguay the mean monthly temperature anomaly was as high as 3°C above the 1961–90 average in January. Between 6 and 11 February, Patagonia experienced above-average temperatures, setting records in several locations. The anomalously warm conditions continued during March–May 2011 (austral autumn) over Argentina and Uruguay.

In contrast, the southern South America winter (June–August) was cooler than average (-0.5°C to -1.0°C) in Chile, central Argentina, and Uruguay. A cold wave between 25 June and 10 July brought cooler-than-average temperatures, 5°C to 10°C below average, for several days. In Argentina, daily minimum temperatures were as low as -16.0°C in Malargüe (Mendoza Province) on 3 July and -7.7°C in Bolivar (Buenos Aires Province) on 6 July. In central Chile, the minimum temperature was -3.0°C in Santiago on 3 July and -4.8°C in Curico on 4 July. These extreme low temperatures during the Southern Hemisphere core winter claimed the lives of five people in Uruguay. The invasion of cold air also brought heavy snowfall. Snow covered half of Argentina and Chile during 6–8 July, including northern Chile (Atacama Desert) and southern Buenos Aires Province where snowfall is rare. According to the Argentine Weather Service, temperature anomalies of -1°C to -2°C were widespread across Argentina during July 2011. Similar conditions were observed in Chile between Valparaiso and Temuco.

During austral spring (September–November) above-average mean temperature anomalies (+0.5°C to +1.5°C) were observed over the entire region (Uruguay, Argentina, and Chile). In September, several maximum temperature records were set in northwestern Argentina. In Santiago (central Chile), the mean maximum temperature of 23.3°C was the highest ever recorded, 4.2°C above average. Meanwhile most of southern South America was cooler than average in October 2011. According to the Argentine Weather Service, several locations in Argentina experienced their coolest October in the last five decades. In Chile, this cooling was more moderate, with anomalies around -1°C.

(ii) Precipitation

During 2011, below-average precipitation across southeastern South America was attributed to the La Niña episode, which began during the latter part of 2010.

In Argentina, the annual rainfall was below the 1961–90 average across much of the region, with eastern Buenos Aires and Cordoba Province being the most affected at 60–80% of normal. In central Chile, annual precipitation was below normal, resulting in the fourth driest year since 1950. In May 2011, several cities in Argentina and Chile recorded their lowest precipitation totals since 1961, including Iguazú (4.0 mm), Río Cuarto (2.0 mm), and Trelew (0.5 mm). The driest anomalies during June–August 2011 were observed across eastern Brazil, Argentina, northeastern Bolivia, and central and southern parts of Chile. Although isolated heavy rainfall impacted these areas, it wasn't enough to alleviate the dry conditions.

Heavy rain fell on 15 July across Uruguay and southern Brazil. The maximum 24-hour accumulated rainfall total was 140 mm observed in Lavalleja and Rocha, both located in Uruguay. In northern Chile's Atacama Desert, a cutoff low pressure system on 3–8 July brought heavy snowfall (up to 20 cm) and strong winds (above 20 m s^{-1}), seriously affecting the mining industry in the high mountains of the Andes and land transportation between Chile, Bolivia, and Argentina.

In Argentina and Uruguay, the drier-than-average conditions were more intense during the second half of the year. However, rainfall in October brought relief to the northern part of the region, and in November to the central and western part of the province of Buenos Aires. In particular, the northern province of Buenos Aires showed deficits in all months during the latter half of the year. Anomalies were the lowest in August, September, and December, reaching values that were 20% of normal. Nine meteorological stations located in northeastern Argentina recorded their lowest December precipitation totals since 1961. In Chile, the driest months were May–July, October, and December. The central region was the most affected, with deficits of 50–60%. The greatest impacts were in agriculture, freshwater resources, and hydroelectric power.

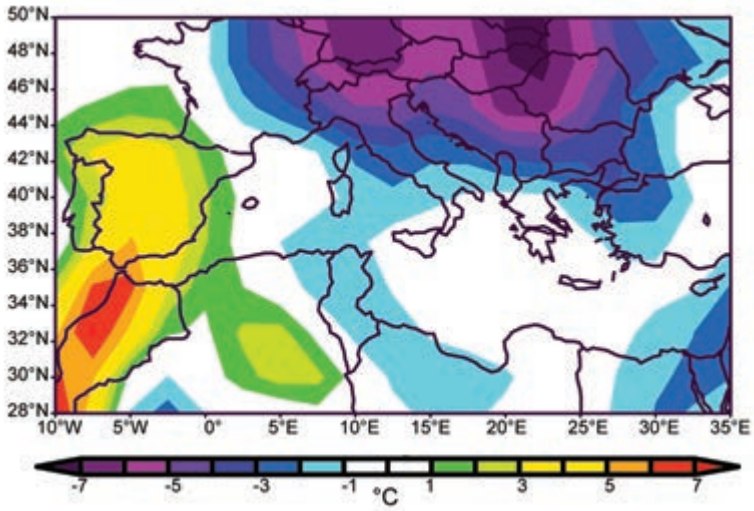

Fig. 7.15. Temperature anomaly (°C) in northern Africa on 2 July 2011. (Source: NOAA/NCEP)

(iii) Notable events

Overall, below-average rainfall prevailed throughout much of Argentina in 2011. The excess precipitation occurred locally and some of the events were very intense. Extreme events occurred in February, April, and August. On 23 February, a severe storm brought heavy rain, hail, and strong winds to various neighborhoods around the capital of the province of Mendoza (western Argentina), resulting in floods and fallen trees. On 26 February, another severe storm affected the province of Catamarca, isolating locations due to overflowing rivers and landslides.

Two days of heavy rain caused a state of emergency in Comodoro Rivadavia city (central-east of Patagonia). A total of 120 mm of rain fell on 12–13 April, almost four times April's monthly average. On 8 August, Iguazú Falls (northeastern Argentina) streamflow increased to eight times its normal flow in only a few hours due to the intense rainfall in southern Brazil.

In northern Chile, intense rainfall occurred during 3–8 July and again on 31 July that affected the Atacama Desert region. Daily totals between 20 mm and 25 mm were observed, where precipitation is typically near zero or less than 5 mm during the month.

e. *Africa*

1) Northern Africa—K. Kabidi and A. Sayouri

This region includes Morocco, Algeria, and Tunisia. The 1971–2000 base period has been used to assess anomalies in both temperature and precipitation in 2011.

(i) Temperature

Generally, both maximum and minimum temperatures were higher than average over the region. The year 2011 was the warmest in the last ten years. The annual maximum temperature averaged between 0.5°C and 3.5°C above normal with the largest anomaly observed in Taza, in the north-central sector of Morocco, south of the Rif Mountain. The annual maximum temperature anomaly was strongly influenced by extreme warm temperatures during the summer season.

During winter, both positive and negative anomalies were observed. The mean temperature anomaly ranged between -2.4°C at Nador in eastern Morocco to +1.5°C in Sidi Slimane in central Morocco. An exceptional cold wave occurred in January and February. The region experienced significant snowfalls, with temperatures reaching -7°C in Algeria. Positive temperature anomalies returned during the spring season, with anomalies greater than +1.7°C. Summer was characterized by exceptional heat waves and ex-

treme temperatures were recorded. June and July temperature anomalies surpassed +4.4°C in Sidi Slimane (Fig. 7.15), as mean temperatures reached 45.3°C and 49°C in Sidi Slimane and Ain Saleh, respectively.

(ii) Precipitation

Overall, the annual precipitation was above average, especially during autumn when rainfall amounts reached 171% of normal in Rabat in Morocco. Several locations recorded rainfall amounts approaching 100 mm in a 24-hour period during this time, resulting in flooding. The winter season was quite active with the development of storms that produced heavy rains approaching 80 mm in Chefchaouen, Morocco, in a 24-hour period, and over 50 mm also in 24-hour period in Tangier, Morocco. In Algeria, a winter storm produced over 60 mm of rainfall in Echelf and Constantine. More storms that produced over 60 mm rainfall in less than 24 hours occurred in the northern areas of Algeria and Morocco during the spring, especially in March and May. Rainfall surpluses exceeded 180% of normal. Summer was dominated by the presence of an anticyclonic system across northern Africa and dry conditions, except for intense heavy rains that fell in northwestern Morocco in early June. During autumn, strong storms produced heavy rains and caused flooding in many locations in Algeria and in Morocco during autumn, especially during October. Records indicated 94.6 mm at Chefchaouen (northern Morocco), 104 mm at Bouchegouf (northeastern Algeria), and 78 mm at El kala (northern Algeria). Rainfall totals averaged 320% of normal in Nador (eastern Morocco).

(iii) Notable events

October and November were marked by a succession of significant heavy rainfall events that led to several floods in Morocco, Algeria, and Tunisia. These events caused important infrastructure damage and loss of human life, especially in Algeria.

Also in Algeria, several forest fires associated with a heat wave and daily temperatures exceeding 49°C, burned at the end of July and the beginning of August. An estimated 15 000 ha of land was affected, according to the Forestry Department of Algeria.

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

Western Africa extends from the Guinea coast to Chad and the Central African Republic. All analyses are based on the 1971–2000 base period.

(i) Temperature

The year 2011 was once again very warm in Western Africa. The monthly temperature remained above average every month and across the region. In January, the temperature was 1.5°C above normal and the greatest anomalies (3.5°C above the 1971–2000 base period) were observed in Mauritania, central Niger, and northern Sudan. The positive anomalies increased in February, with temperatures 3.5°C above average in Niger, western Chad, and northern Nigeria. In March, temperature decreased, but maintained positive anomalies (> 2.5°C) in Mali, northern Burkina Faso, and western Niger with highest anomalies (> 3.5°C) over central Mali and western Niger. April had a major decline in temperature anomalies, with (< 1.5°C) over northern Mauritania and northwest Mali that persisted in May with the temperature anomalies (< 1.5°C) covering the central part of the Sahel. Unlike the previous year, the June 2011 temperature anomalies (> 1.5°C) intensified spatially over parts of Mauritania, Mali, Burkina Faso, Ghana, Benin, Togo, Niger, and Chad, with an epicenter (> 2.5°C) over northwest Mauritania. In July, temperature anomalies

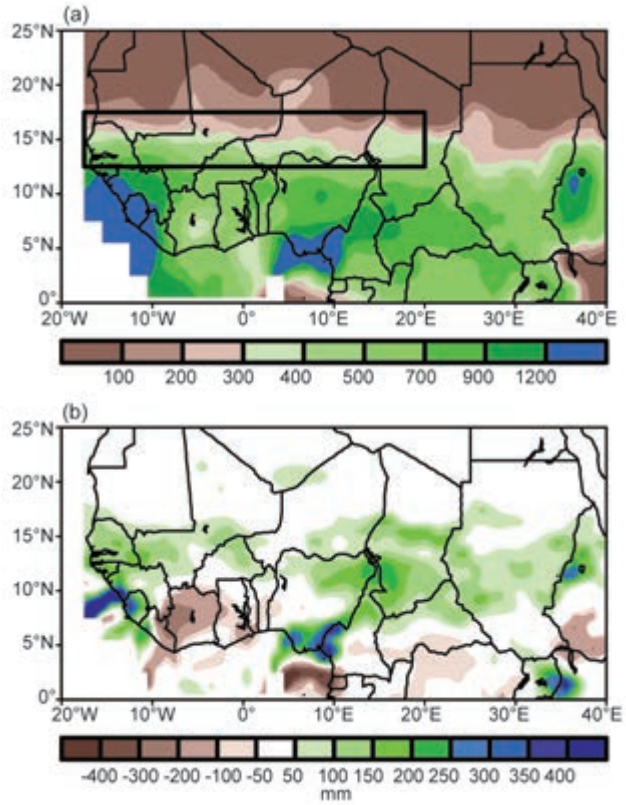

Fig. 7.16. Jun–Sep 2011 (a) rainfall (mm) for Western Africa and (b) anomalies (departure from the 1971–2000 base period). The boxed region indicates the approximate boundaries of the Sahel region. (Source: NOAA/NCEP)

(> 1.5°C) were observed over parts of western, central, and eastern Sahel. Temperature anomalies in August ranged between -1°C and 1°C over the continent, but peaked in September with anomalies of +1.5°C to +2°C covering parts of Mauritania, Mali, Burkina Faso, Ghana, Benin, Togo, Niger, and northwestern Nigeria, and intensified in October over these parts with an epicenter greater than 2.5°C, over northwest Mauritania. In November, positive temperature anomalies from 1.5°C to 2.0°C covered western part of West Africa, with a weak epicenter > 2°C over northwestern Guinea. In December, the temperature anomalies were generally normal over West Africa.

(ii) Precipitation

The year 2011 was characterized by overall near-average conditions (compared with the 1971–2000 base period) across most areas in West Africa (NOAA gridded gauge precipitation analysis, PREC/L). Rainfall totals from June to September ranged between < 100 mm in the northern part of the Sahel to >1200 mm in the western Guinean coast, and along the coastal border of Nigeria and Cameroon (Fig. 7.16a). The rainy season was slightly above average across the Sahel and portions of the Gulf of Guinea. However, rainfall amounts were much less than in 2010, the wettest year in the Sahel in over 50 years. Rainfall was 50 mm – 100 mm above average across the Sahel (Fig.7.16b). Surpluses over 200 mm were observed along the coast of Guinea and along the south border between Cameroon and Nigeria. Rainfall was much below average over most areas in Cote d'Ivoire and portions of western Ghana, with deficits between 100 mm and 300 mm.

(iii) Notable events

Overall, the June–September rainy season had a slow start, an early withdrawal, and dry spells, especially in central Sahel. This resulted in poor harvests, food shortages, and scarcity of water availability in affected areas that called for international humanitarian relief assistance. However, in the western end of the Sahel, the West African monsoon system intensified in August, with excessive rains and flooding, especially in Guinea and Mali. Torrential rains during 23–24 August led to floods in the northwestern, central, and northeastern sectors of Guinea, causing significant material damage, and leaving more than 4000 people homeless.

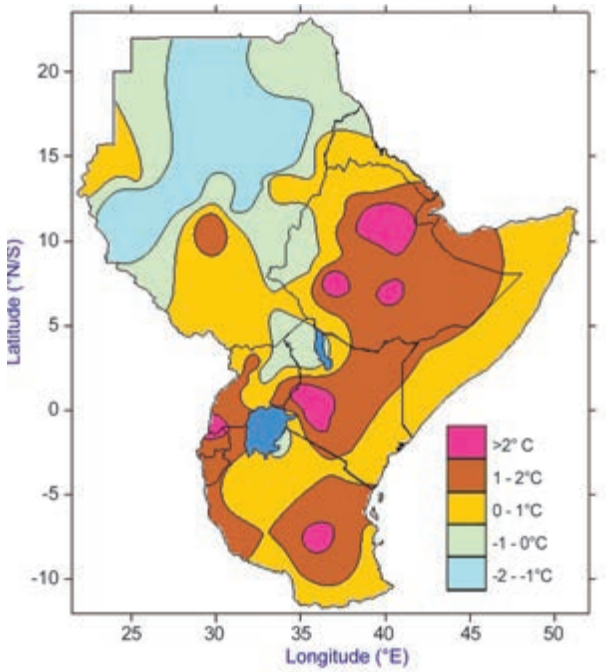

Fig. 7.17. Minimum temperature anomalies for 2011 (°C, 1961–90 base period). (Source: IGAD Climate Prediction and Applications Centre)

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

The Greater Horn of Africa (GHA) can broadly be divided into three sectors. The northern sector encompasses northern and central Somalia, Djibouti, Eritrea, Ethiopia, Sudan, and South Sudan. The equatorial sector covers southern Somalia, Kenya, Uganda, Burundi, Rwanda, and northern Tanzania. The southern sector covers central and southern Tanzania.

March–May marks the main rainfall season or "Long Rains" over the equatorial sector, while a second rainfall season, the "Short Rains" is observed from late September to early December. June to early September marks the rainfall season over the northern sector and the coldest season over the equatorial sector. The western highlands of Kenya also experience significant rainfall during this season. The southern sector receives rainfall from December to February. The base period for this section is 1961–90 unless otherwise stated.

(i) Temperature

In eastern Africa, noteworthy minimum temperatures, as opposed to mean and maximum temperatures, have been observed recently; hence, these temperatures are discussed in this section. Warmer-than-average minimum temperature anomalies prevailed over much of the GHA, except for northern and central Sudan in the northern sector of the region, and

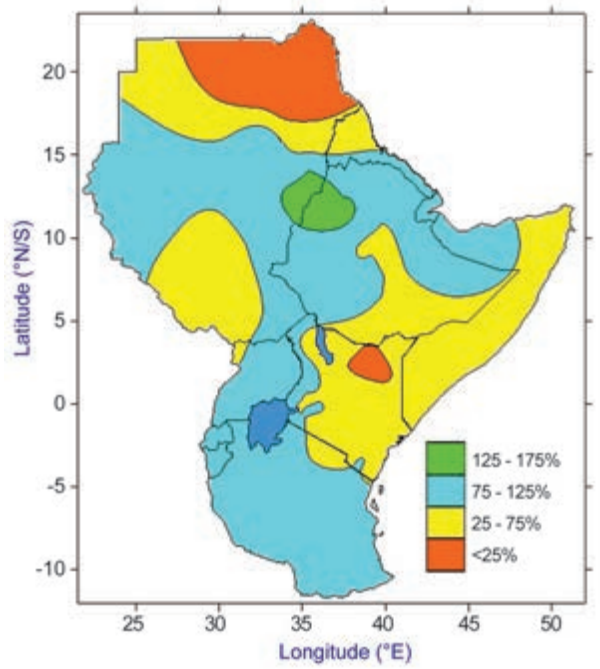

Fig. 7.18. Rainfall anomalies (% of normal) for March–May 2011 (1961–90 base period). (Source: IGAD Climate Prediction and Applications Centre)

portions of northwestern and northeastern Uganda in the equatorial sector of the region. Minimum temperature anomalies exceeded +2°C in central Tanzania, southwestern Kenya, and parts of Ethiopia (Fig. 7.17). Mombasa, Kenya, reported the highest average January minimum temperature in the last 11 years (departure computed based on 2000–10 mean). The minimum temperature also ranked among the highest during most months in 2011 at this location (not shown).

(ii) Precipitation

From December 2010 to February 2011, parts of western Ethiopia, southern Uganda, western Kenya, and northwestern, western, eastern, and southern Tanzania received between 75% and 125% of their long-term average rainfall (1961–90). However, northeastern Kenya, much of Somalia, much of central and eastern Ethiopia, Djibouti, Eritrea, northern and central Sudan, received less than 25% of the long-term average rainfall. Many stations in this sector recorded rainfall totals below the 40th percentile, based on the 1961–2010 period.

March–May is the main rainfall season over much of the equatorial sector. The eastern parts of this sector received between 25% and 75% of their long-term average, while the western equatorial sector and much of the southern sector received between 75% and 125% of the long-term average (Fig. 7.18). The low rainfall, which followed the October–December 2010 below-average rainfall season in this sector, resulted in an inadequate supply of water for domestic and industrial use, depleted pasture stocks, increased food insecurity, and conflicts between communities over scarce resources.

June–August (JJA) marks the main rainfall season over the northern sector. The western equatorial sector also receives substantial rainfall during this period. The western, central, and southeastern parts of the northern sector received between 75% and 125% of the JJA long-term average rainfall (not shown). Much of the central and western parts of the equatorial sector of the GHA received more than 125% of the long-term average rainfall.

September–November (SON) marks the second rainfall season known as "Short Rains" over the equatorial sector, while December marks the onset of the rainfall season over the southern sector. During SON 2011, most areas in the Greater Horn of Africa received above-average rainfall, except for Tanzania and the northern areas of Ethiopia and Somalia. However, much of Tanzania, especially the

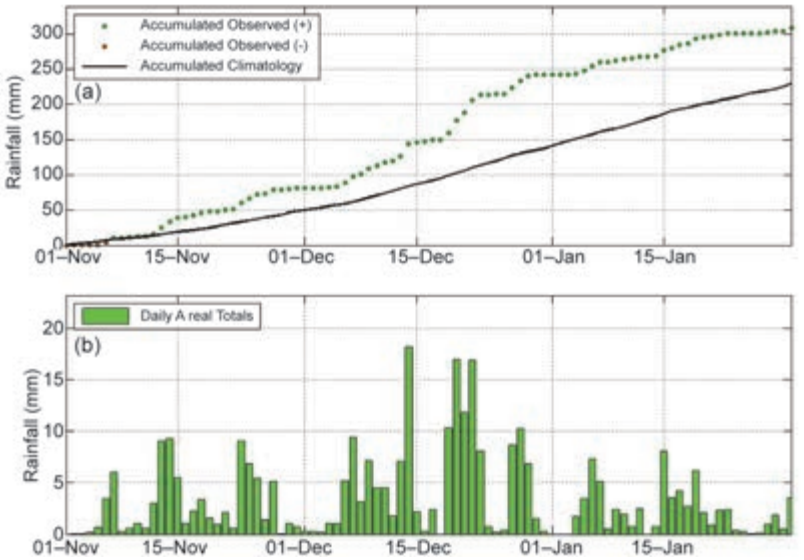

Fig. 7.19. Daily rainfall evolution (mm) over north-central Tanzania derived from satellite and rain gauge measurement for the period Nov 2011–Jan 2012. (a) Solid line indicates cumulative rainfall climatology for the period; dotted line indicates cumulative rainfall from Nov 2011 to Jan 2012. (b) Bars show daily rainfall estimates. (Source NOAA/NCEP)

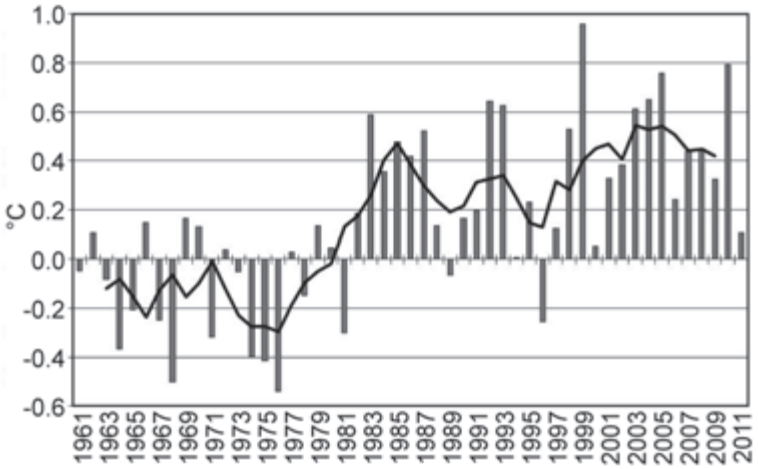

Fig. 7.20. Annual mean temperature anomalies (°C, 1961–90 base period) for 27 climate stations in South Africa, 1961–2011. The bold black line indicates the five-year running mean. (Source: South African Weather Service)

north-central part, received above-average rainfall in December (Fig. 7.19). The enhanced rainfall over the equatorial and southern sectors during the SOND 2011 season resulted in improved availability of water for domestic and industrial use, and high prospects for livestock production due to improved pasture conditions. However, the recurrence of flash floods during the season caused challenges to manage outbreak of water-borne diseases and post-harvest storages. The enhanced rainfall activity was associated with warmer-than-average sea surface temperatures over the western Indian Ocean during the SOND 2011 season, which corresponds to the positive phase of Indian Ocean dipole (see section 4h).

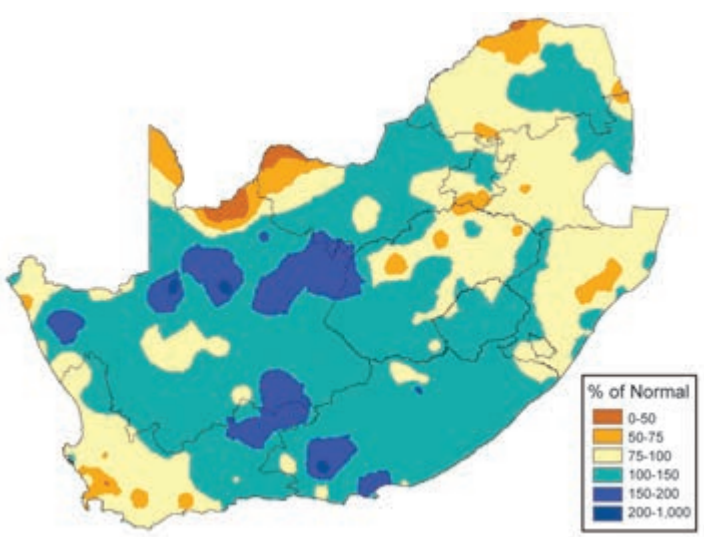

Fig. 7.21. Rainfall anomalies (% of normal, 1961–90 base period) for South Africa and Lesotho for 2011. (Source: South African Weather Service)

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

This region includes the countries south of 10°S with emphasis on the Republic of South Africa.

(i) Temperature

For the Republic of South Africa, the annual mean temperature anomalies for 2011, based on the preliminary data of 27 climate stations, was about 0.1°C above the 1961–90 base period. Although 2011 was coolest year of the last 11 years, the warming trend indicated by the data of these particular climate stations is still statistically significant at the 5% level. Figure 7.20 shows that the mean temperatures of the past 15 years were all above normal.

(ii) Precipitation

The climate of South Africa is very diverse. The complex topography and the different types of rainfall systems influence mean precipitation. Summer rainfall typically occurs from October to April, with a peak in December through March. January–March 2011 precipitation was characterized by above-average rainfall over most of the interior, but was drier than normal over the coastal regions and the northeastern interior. During April–June, almost the whole country received above-average rainfall, except for some isolated regions in the far southwest and northeast. July–September was dry over most of the interior, as well as the west coast. However, above-average rainfall was received over most of the coastal regions, as well as parts of the northeastern interior. Below-average rainfall was seen in October–December over most of the interior, but above-average rainfall prevailed in the western, southeastern, and eastern coastal regions. Above-average rainfall was also received over significant parts of the eastern interior. The annual rainfall anomaly (Fig. 7.21) suggests near-average conditions over much of northeastern South Africa, including parts of the Maize Triangle and the Western Cape Province. Rainfall was above average across the interior of South Africa, with rainfall approaching 200% of the climatological mean in some areas, especially in the Northern Cape Province.

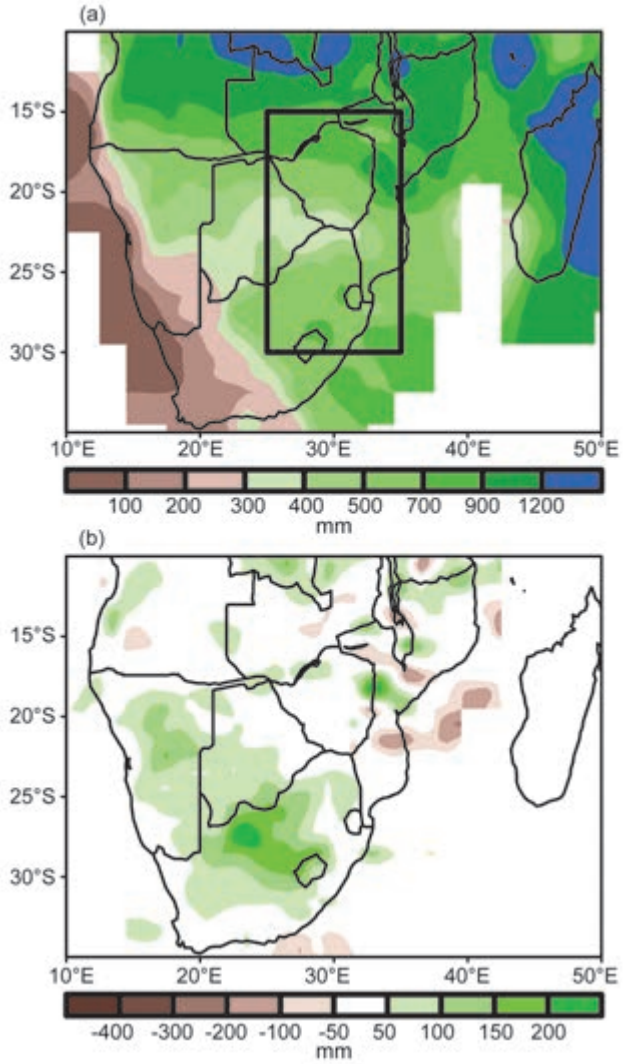

Fig. 7.22. Nov 2010–Apr 2011 (a) rainfall (mm) for Southern Africa and (b) rainfall anomalies (departure from the 1971–2000 base period). (Source: NOAA/NCEP)

For southern Africa, rainfall totals from November 2010 to April 2011 ranged from less than 100 mm along the west coast of South Africa and coastal Namibia, to more than 1200 mm along the border between northern Zambia and the Democratic Republic of Congo, and along the northern part and east coast of Madagascar (Fig. 7.22). Southern Africa austral summer features two basic climate zones. The southwestern sector is much drier on average than the remainder of the region. The area of maximum precipitation in the northern part of the region observed rainfall between 700 mm and 1200 mm. To the south, rainfall in the crop areas of eastern Botswana, Zimbabwe, central Mozambique, and northeastern South Africa received 300 mm – 800 mm.

(iii) Notable events

Persistent heavy downpours during January and February 2011 across portions of Zambia, Zimbabwe, and Mozambique elevated water levels along the Zambezi, Pungoe, Buzi, Save, Limpopo, Incomati, and Maputi Rivers in central and southern Mozambique, and caused flooding that displaced local populations and damaged crops. In particular, increased discharges from the Cahora Bassa, Kariba, and the Massingir Dams triggered flooding downstream on the Zambezi River and the Limpopo River, respectively. The flooding in January in South Africa caused extensive damage countrywide, with 33 municipalities in eight provinces declared disaster areas, according to the 2011 update of the South African Weather Service CAELUM database (which also includes other events in South Africa). The worst hit areas were in the Northern Cape, North-West, and KwaZulu-Natal Provinces, where 19 people lost their lives. The flooding affected more than 14 400 households and damaged more than 13 000 houses. In KwaZulu-Natal alone, damage was estimated at about $88 million (US dollars). Damage to roads and bridges was estimated at $38 million (US dollars) while damage to infrastructure was estimated at $18 million (US dollars). The Vaal, Bloemhof, Gariep, and Vanderkloof Dams, which include the largest dams in South Africa, reached their capacity. The Orange River burst its banks between Upington and Kakamas in the Northern Cape Province. During March, heavy rains caused havoc in Johannesburg and Pretoria. Three people drowned and temporary housing along the Jukskei River, between the two cities, was washed away. Heavy rains also fell in Reivilo, in North-West province, towards the end of April and beginning of May, resulting in damaged roads. Farmers could not transport their animals to auctions and persistent wetness led to various animal diseases. A hailstorm in May damaged or destroyed 53 houses in the Hoyi area of Mpumalanga province, with 341 people affected. In the Eastern Cape province snowfalls led to the closure of the Barkly Pass between Barkly East and Elliot. In addition, roads in the Sneeuberg Mountain area near Nieu-Bethesda were also damaged.

Unseasonably heavy rain fell in June over the Gauteng, KwaZulu-Natal, and Free State provinces, causing localized flooding. In KwaZulu-Natal, 200 people were evacuated from the Powerton informal settlement near Durban after water levels rose in the low-lying areas. Sixteen people were rescued from a farm near Bloemfontein in the Free State province after the Renosterspruit River burst its banks.

Heavy rain also affected the Western Cape province as well as towns along the Garden Route along the south coast. Roads were submerged, houses flooded, schools closed, and people were evacuated. According to reports, 1895 households and 7300 people were affected. In the Eastern Cape province at least 6 people drowned and 1400 people were displaced following flooding in Port Elizabeth, Uitenhage, Butterworth, and Lusikisiki. Eight people from Palmiet River Primary School, about 30 km outside Uitenhage, were rescued by helicopter after the bridge between the school and the main road collapsed.

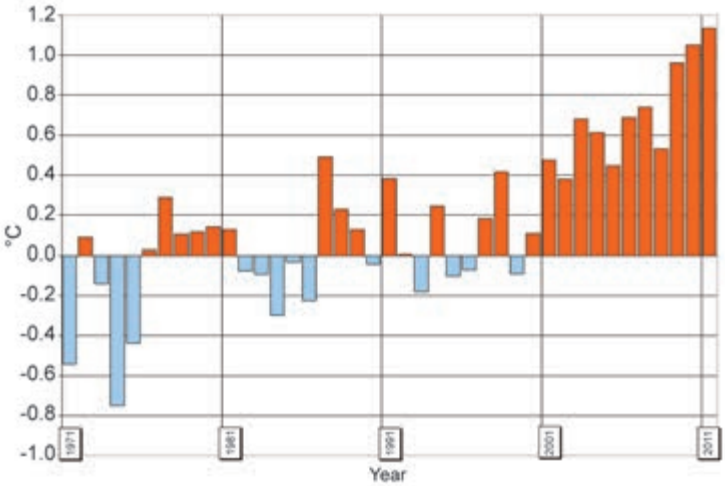

Fig. 7.23. Annual mean temperature anomalies (°C) in Réunion (average of 10 stations) for the period 1971–2011 (1971–2000 base period). (Source Météo France, La Réunion)

The volcanic ash cloud that originated from the Puyehue-Cordon Caulle volcanic complex in south-central Chile, South America, moved over the southern parts of the country on 18–19 June and affected flights to and from Cape Town, Port Elizabeth, and East London.

In Namibia, snow fell on 7 June on the Spreetshoogte Pass between Windhoek and Sossusvlei, which is a very unusual occurrence in this region.

During July a veld fire, driven by strong winds, caused extensive damage to about 8500 ha over at least 17 farms in the district of Ermelo, in Mpumalanga province. Damage was estimated at more than $1.3 million (US dollars). Two people died and extensive damage occurred in East London, Eastern Cape, following heavy rain accompanied by hail and strong wind. People were rescued from their houses and vehicles after they were surrounded by flood waters. Gale-force winds also caused extensive damage to property in places in the Western Cape. Heavy snowfalls occurred over the Free State, KwaZulu-Natal, Western and Eastern Cape. Major roads in the four provinces were closed due to the heavy snowfall and ice on the roads. In addition, very cold conditions with rain and snow were reported in most parts of the country. Several towns were snowed in, with schools and businesses closed, power supplies disrupted, and people stranded on roadsides. Some farmers sustained severe stock losses due to the heavy snow and accompanying strong winds.

In August, 13 people were killed when two Albatross airplanes crashed into the Mamotswiri Peak mountains near Tzaneen, Limpopo province, during bad weather conditions. Snowfall caused the closure of Van Reenen's Pass, between the Free State and KwaZulu-Natal provinces. Veld fires fanned by gale-force winds raged out of control in North-West and the Free State provinces where two people lost their lives.

During October, 1 person died, 166 people were injured, and 2790 were left homeless after a tornado and heavy rain hit the Duduza settlement near Nigel in the Gauteng province. More than 550 homes were destroyed and a disaster area was declared. A tornado also hit the community of Meqheleng in Ficksburg, in eastern Free State, leaving 1 person dead and affecting about 405 people. Heavy rain, hail, and strong winds left several families homeless in the Tsetse village outside Ventersdorp in North-West province. Thirteen people lost their lives in November when heavy rain fell over Paulpietersburg, Pietermaritzburg, and Durban in KwaZulu-Natal. Seven hundred houses were destroyed and thousands of people were displaced.

5) Western Indian Ocean countries—G. Jumaux and F. Hassane

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

(i) Temperature

For Réunion, 2011 was the warmest year on record since 1971, with an annual mean temperature anomaly of +1.14°C (+0.77°C and +1.51°C for annual minimum and maximum temperature, respectively). Réunion also had its warmest June, July, August, and November monthly temperatures since 1971 (Fig. 7.23). For the Union of Comoros, the mean temperature anomaly was once again above its 1971–2000 long-term average.

SIDEBAR 7.2: AFRICA: THE DROUGHT OF EAST AFRICA IN 2011—W. M. THIAW

In 2011, East Africa witnessed one of its most severe droughts in several decades. The drought resulted from two consecutive failed rainy seasons in September–December 2010, (Short Rains season), and in March–May 2011 (Long Rains season), and was considered the worst drought in 60 years according to the UN Food and Agriculture Organization (FAO). Rainfall was much below average across East Africa during the 2011 Long Rains (Fig. SB7.3). The season was off to a slow start in February and March. It was also marked by frequent dry spells and an early withdrawal of the rains. Some localities in eastern Africa did not receive rainfall during the entire season. The areas that were most affected by the drought included central and northeastern Kenya, southeastern Ethiopia, and southern Somalia. The lack of rainfall during this season adversely affected crop production and pastures in many sectors in this subregion. River basins such as Juba, Mara, and Shebelle saw their resources depleted, impacting water availability for wildlife and pastoral communities. These conditions led to the worst food crisis in this region, which started in May 2011. The UN officially declared famine in localities in Somalia. Millions of people were in immediate need for humanitarian assistance and many people died of diseases related to hunger or malnutrition.

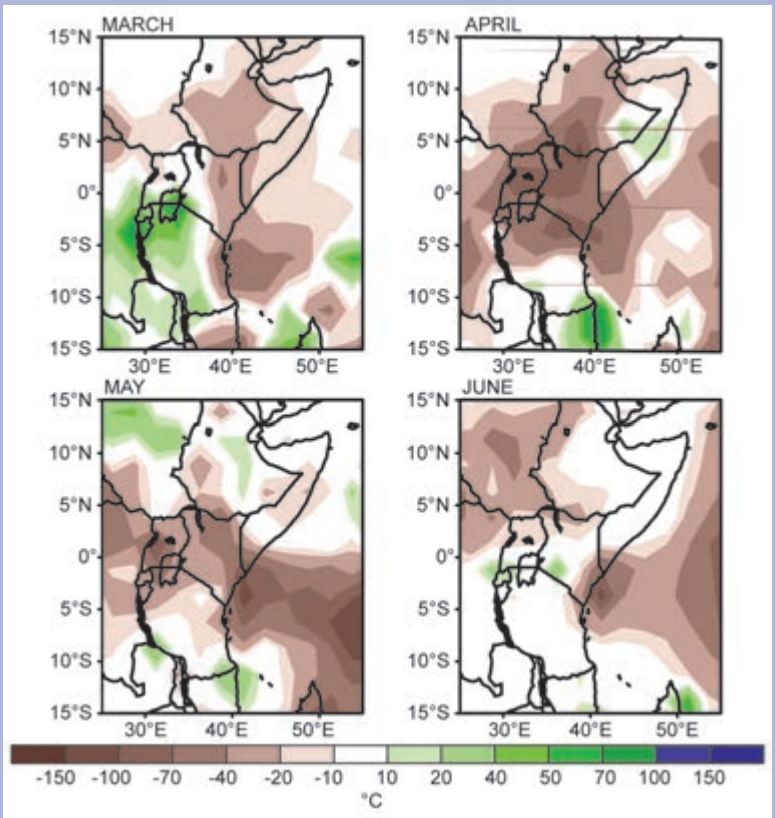

Fig. SB7.3. Monthly rainfall anomalies (mm) for March, April, May, and June 2011 for eastern Africa (departure from the 1971–2000 base period). (Source: NOAA/NCEP)

The drought was partially associated with the La Niña episode of 2010/11. While the relationship between La Niña (El Niño) and the Short Rains has clearly been established, and is known to be conducive to below- (above-) average rainfall in eastern Africa (Ropelewski and Halpert 1987), the ENSO teleconnection for the March–May season are not well defined in the scientific literature. This is due in part to the fact that SST anomalies in the tropics are weakest during the spring season. In addition, weather systems during the March–May season are closely tied to the oscillation of the ITCZ over Africa, and topography plays a particularly important role. However, Lyon and DeWitt (2012) found that the rainfall deficit in East Africa during March–May 2011 is part of a long-term precipitation downward trend that can be linked to SST changes in the tropical Pacific. Persistent low-level winds from northeastern Africa and the presence of a midlevel subtropical ridge maintained the ITCZ farther south and contributed to the suppressed rainfall activity.

(ii) Precipitation

For Réunion, the annual precipitation amount was about 85% of the long-term average and was the 15th driest year since 1971; however, the western part of the island received rainfall that was about 160% of normal. In contrast, 2011 was the driest year in the historical record in the southern areas of the region, where only 50% of the long-term average rainfall was recorded. For the Union of Comoros precipitation was about 26% of long-term average, while the northern part of Grande Comoros was dry during 2011.

(iii) Notable events

Tropical Cyclone Bingiza made landfall in northeastern Madagascar on 14 February 2011 as an intense storm with maximum sustained wind of 165 km hr^{-1}. The storm weakened as it crossed northern Madagascar and emerged into the Mozambique Channel

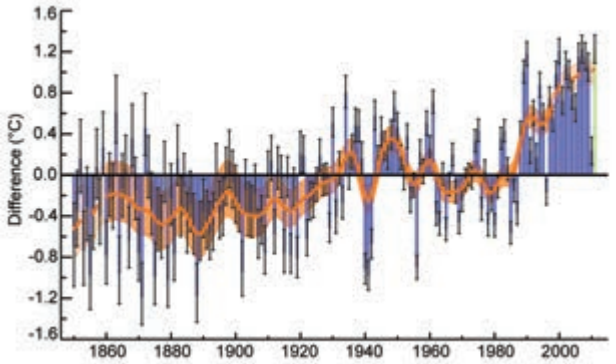

Fig. 7.24. Annual average land surface air temperature anomaly (°C) for Europe (35°N–75°N, 10°W–30°E) from 1850 to 2011, relative to the 1961–90 base period. The blue bars show the annual average anomaly values and the black error bars indicate the 95% confidence range of the uncertainties. The green bar is the annual value for 2011. The smooth orange line shows the annual values after smoothing with a 21-point binomial filter. The dashed portion of the line indicates where the smoothed curve is affected by the choice of end-point padding and is liable to change in future. The hatched orange area indicates the 95% confidence range on the smoothed values. Data are from the CRUTEM3 dataset (Brohan et al. 2006).

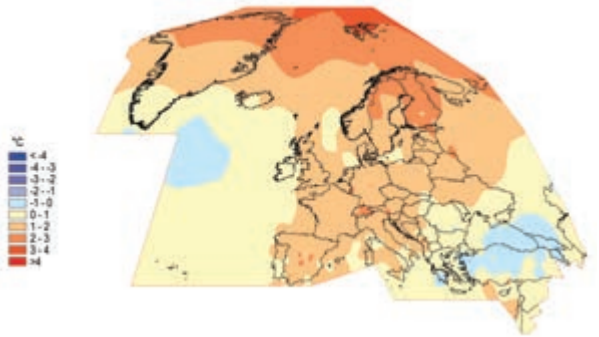

Fig. 7.25. Annual mean temperature anomalies for 2011 in Europe and over the North Atlantic (°C, 1961–90 base period) based on CLIMAT and ship observations. (Source: Deutscher Wetterdienst)

before turning southward to move across western Madagascar. The storm killed 22 people and injured 13 others.

f. Europe

1) Overview—K. Trachte, A. Obregón, P. Bissolli, J. J. Kennedy, D. E. Parker, R. M. Trigo, and D. Barriopedro

The standard base period used in this section is 1961–90 for temperature and precipitation, unless otherwise specified. Changes in the baseline among European countries conform to different standards applied by the national weather services. All seasons mentioned in this section refer to the Northern Hemisphere.

More detailed information about Europe can be found in the *Monthly Bulletin on the Climate in RA VI – Europe and Middle East*, provided by the WMO RA VI Pilot Regional Climate Centre on Climate Monitoring (RCC-CM, http://www.dwd.de/rcc-cm).

The mean annual air temperature in 2011 for Europe tied with 2007 as the warmest year on record; however, given the observational uncertainties, it is not definitively distinguishable from any of the six warmest years since 1850 (Fig. 7.24). According to the CRUTEM3 dataset (Brohan et al. 2006) the land surface air temperature for the European region (35°N–75°N, 10°W–30°E) was 1.23°C ± 0.14°C above the 1961–90 average. Most of Europe had anomalies of +1°C to +2°C (Fig. 7.25). Only parts of southern Greece, most of Turkey, the eastern Black Sea areas, and the western Caucasus region were below average. All seasons except winter were characterized by above-average temperatures throughout most of Europe. This reflects the continuation of the long-term warming trend in Europe.

Winter season (DJF 2010/11) was anomalously cold in large parts of Europe (Figs. 7.26, 7.27, DJF), mainly due to the very cold December 2010, when

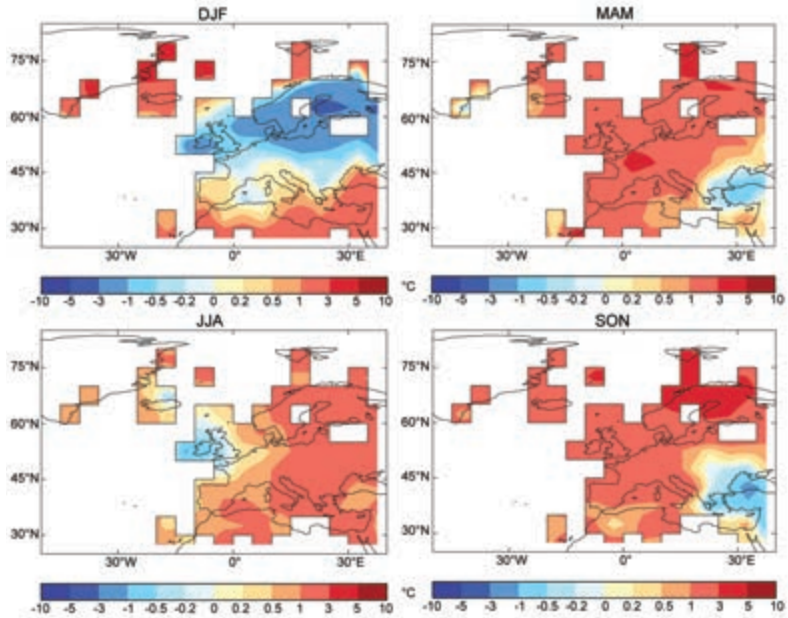

Fig. 7.26. Seasonal anomalies (°C, 1961–90 base period) of gridded land surface temperature for Europe. Data from the CRUTEM3 dataset (Brohan et al. 2006).

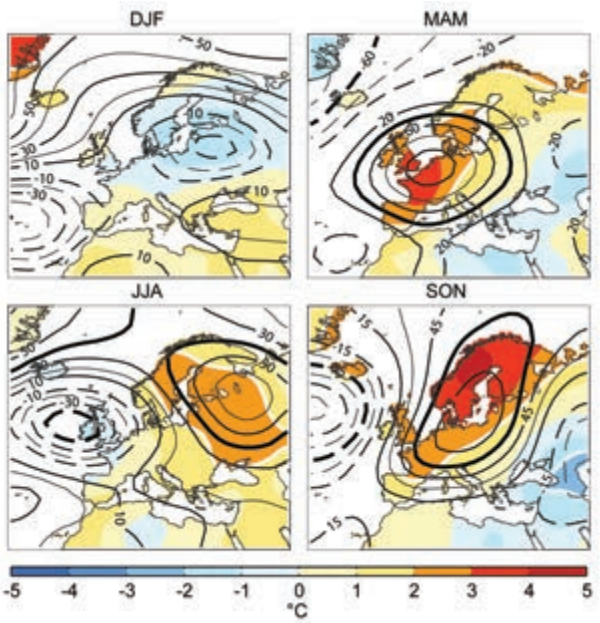

Fig. 7.27. Seasonal anomalies (1961–90 base period) of 500-hPa geopotential height (contour, gpm) and 850-hPa temperature (shading, °C) using data from the NCEP/NCAR reanalysis. Winter (DJF), spring (MAM), summer (JJA), and autumn (SON). Black (white) thick lines highlight those geopotential height (temperature) contours with all the encircled grid points having absolute anomalies above their 1-sigma level of the base period.

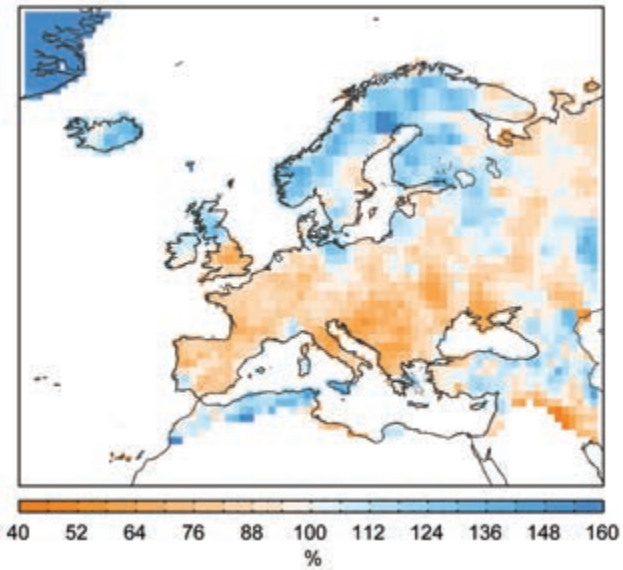

Fig. 7.28. European precipitation totals (% of normal, 1961–90 base period) for 2011. Only grid points with annual normals above 15 mm month^{-1} are represented. (Source: Global Precipitation Climatology Centre; Schneider et al. 2011)

the standardized North Atlantic Oscillation (NAO) index reached strong negative values (-1.85) and the associated weakening of westerly winds reduced warm advection into the north of the continent. Instead, cold air from Russia extended far to the west. In February 2011, a cold trough formed over Russia, leading cold Arctic air to Scandinavia and eastern Europe. Thus, northern and eastern Europe were particularly cooler than average in winter 2010/11, with seasonal anomalies below -1°C over large areas, reaching -4°C in small areas of northwestern Russia. In contrast, Greenland, Iceland, and the Middle East had much-warmer-than-normal air temperatures. Greenland and Iceland were influenced temporarily by a mild Atlantic airflow. Southern Europe had winter temperatures near or slightly-above normal; most of this area (except Iberia) was under prevailing high pressure, particularly the eastern Mediterranean region.

Spring (MAM) was dominated by well-above-normal air temperatures across most European areas with anomalies exceeding +3°C in the west (Figs. 7.26, 7.27, MAM) due to unusually frequent high pressure systems over continental Europe that also brought record-breaking sunshine. Ireland, the United Kingdom (UK), Netherlands, Luxembourg, France, Spain, Germany, Switzerland, and Austria experienced a record or near-record warm spring. Only southern Greenland, a larger area around the Black Sea, and the Middle East were outside this high-pressure zone and had below-average temperatures.

Mean air temperatures in summer (JJA) were also above normal in large areas of Europe, particularly over eastern Europe (Figs. 7.26, 7.27, JJA). Only central parts of Iceland, Ireland, the UK, and northwestern France experienced below-average temperatures. This east-west temperature dipole was associated with predominance of lower (higher) than usual geopotential height anomalies over the western (eastern) half of the continent (Figs. 7.26, 7.27, JJA) and some resemblance to the summer NAO pattern, which displayed strong negative values (-1.4). While not as hot as 2010, it was a hot summer in eastern Europe, with seasonal mean anomalies above +2°C over the Baltic countries and of +3°C to +4°C in western Russia; Moscow had its third warmest summer on record (Barriopedro et al. 2011).

Autumn (SON) was warmer than average in most European countries, especially in northern and western Europe, Greenland, the Iberian Peninsula, and the western Mediterranean Sea, where temperature anomalies exceeded +1 to +2°C, reaching more than +3°C in northern Scandinavia. Several blocking patterns at high latitudes favored the extremely warm conditions over Scandinavia (Figs. 7.26, 7.27, SON). The blocking was particularly strong in November,

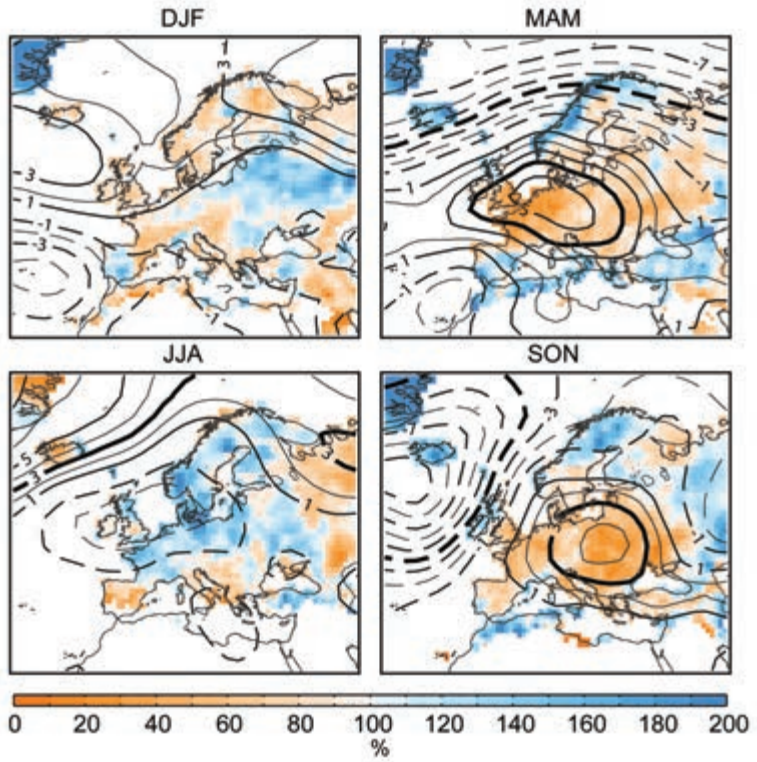

Fig. 7.29. Seasonal anomalies (%, 1961–90 base period) of sea level pressure (hPa) from NCEP/NCAR reanalysis (contours). Colored shading represents the percentage of seasonal mean precipitation compared with the 1961–90 climatology from the monthly Global Precipitation Climatology Centre (GPCC) precipitation dataset. Only grid points with climatological mean (1961–90 reference period) seasonal precipitation above 15 mm month^{-1} are represented. Thick black lines highlight those sea level pressure anomalies having absolute anomalies above their 1-sigma level of the base period.

which was very warm, relative to normal in northern and western Europe, although it was cooler than average in the Middle East, Turkey (-3.2°C anomaly), and the eastern Black Sea regions, and locally on the northern Balkan Peninsula, in relatively good agreement with the extreme positive phase (2.1) of the east Atlantic / western Russia pattern.

In December 2011, the large-scale circulation pattern over Europe changed considerably. The blocking high retreated to Russia, and a mild westerly airflow reached large parts of Europe. The region covered by above-normal temperatures therefore extended to include eastern and northern European regions, with anomalies of more than +4°C (eastern Scandinavia, northern and central European Russia, the Baltic countries, Belarus, and northern Ukraine). December was cooler than normal only in the eastern Mediterranean area, the Middle East, and the northern North Atlantic. It was characterized by strongly positive values of the NAO (2.2).

Precipitation totals in 2011 were above normal over Turkey, Scandinavia, and some other areas of northern Europe (Fig. 7.28). Most of the rest of Europe was frequently affected by anticyclonic systems and, consequently, had below-average annual precipitation totals, particularly the Balkan Peninsula, northern Italy, France, and some other regions of western Europe, where accumulated totals were nearly one-third below their normal. Many areas of the Mediterranean experienced year-round dry conditions, particularly acute in autumn, except the southernmost regions of Europe, which were affected by relatively frequent heavy rainfall episodes.

Most of Europe received near- or below-average precipitation in winter 2010/11 (Fig. 7.29, DJF). Only Greenland, the Iberian Peninsula, and some areas in eastern Europe and Turkey experienced higher-than-normal precipitation totals of 140–180% over large areas, consistent with the canonical precipitation pattern associated with negative NAO phases.

Spring 2011 was extremely dry in England and Wales, western, central, and eastern Europe, and northern Italy, as well as the Balkan Peninsula, except Greece (Fig. 7.29, MAM), with large areas recording accumulated totals below 50% of their normal (see Sidebar 7.3). In contrast, northern Europe (especially Greenland, Iceland, Scotland, and the whole Norwegian west coast) and southern Europe (southern and eastern Iberia, southern Italy, Greece, Turkey, the Middle East, and the Caucasus region) received higher-than-normal precipitation totals. This anomalous precipitation configuration is representative of the northward (and southward) shift of Atlantic storm tracks, as a consequence of blocking highs over northern Europe (Trigo et al. 2004).

The pattern was somewhat reversed during summer (Fig. 7.29, JJA). The blocking high over northern and eastern Europe caused Atlantic low pressure systems to cross western and central Europe, but they were then deflected to the north. Heavy rainfall during summer resulted in precipitation totals of up to 180% of normal in northern and central Europe. Northwestern Russia, the Balkan Peninsula, southern Italy, and Iberia, as well as Greenland and

Iceland, were all under the influence of positive height anomalies and hence experienced a dry season with summer precipitation totals as low as 50% of normal in some regions of these areas.

Similar to spring, the weather conditions in most areas of continental Europe were dominated by persistent high pressure systems during autumn (see Sidebar 7.3). These systems were associated with very dry conditions in northern Iberia, central and western Europe, and the Baltic States, as well as Italy, the Balkan Peninsula, and the western part of eastern Europe (Fig. 7.29, SON). In November, when high pressure became strongest especially over southern central Europe, less than 10mm fell in many places during the month, which corresponds to nearly 10% of normal in some regions of central Europe. There was 50% below-normal precipitation in Turkey when NAO index was positive in November. There is a negative relationship between the NAO index and Turkey's precipitation.

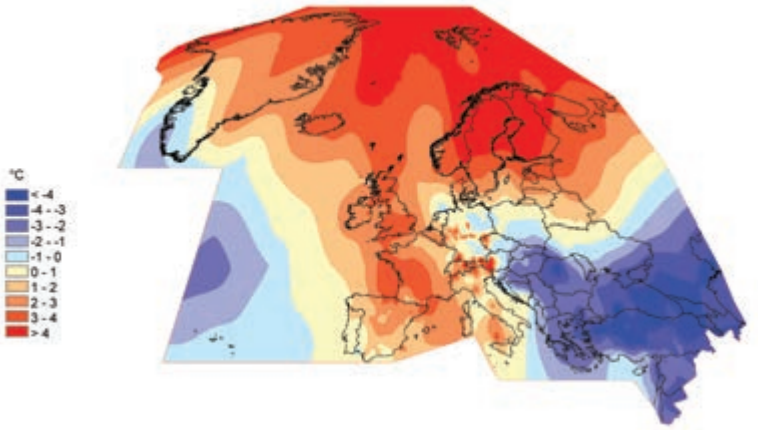

Fig. 7.31. November 2011 mean temperature anomalies in Europe (°C, 1961–90 base period). (Source: Deutscher Wetterdienst)

In December, a very strong frontal zone was established over the northern middle latitudes, which separated humid air in the north from drier air in the south. Dryness dominated most of the Mediterranean area, the Iberian Peninsula, and the Middle East, as well as the Caucasus and part of the Balkan Peninsula. Conversely, the western, central, northern, and eastern regions of Europe experienced very wet conditions in December.

Of note, the NAO index was markedly negative in most of the winter and summer seasons. In contrast, it was positive during the dry periods of 2011 (February–April and September–November), indicating that a stronger-than-normal zonal airflow component existed, but did not affect most of the European continent due to highly persistent continental blocking conditions. (see section 2e1).

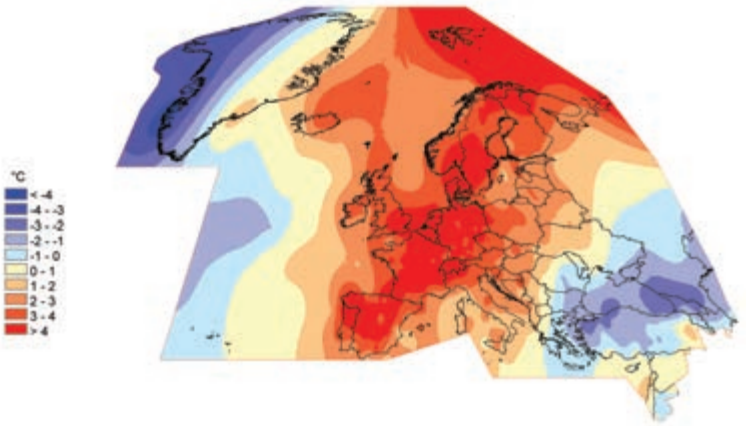

Fig. 7.30. April 2011 mean temperature anomalies in Europe (°C, 1961–90 base period). (Source: Deutscher Wetterdienst)

2) Central and Western Europe—K. Trachte, A. Obregón, P. Bissolli, J. J. Kennedy, D. E. Parker, M. Kendon, and J. Prior

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

(i) Temperature

Most of central and western Europe was warmer than average in 2011 (Fig. 7.25), with anomalies around +1°C to +2°C. The United Kingdom (UK) had its second warmest year since at least 1910. France saw its warmest year since 1900, Luxembourg since 1947, Switzerland since 1864, and Austria's summits since 1851 when records began.

Winter was near or cooler than normal in all areas of central and western Europe (Figs. 7.26, 7.27, DJF), with December the coldest winter month. Remarkably negative pressure anomalies of -12 hPa over central North Atlantic during this month led to a highly negative NAO index (-1.85) and more easterlies. Many countries experienced one of their coldest Decembers on record, but the winter as a whole was less cold than winter 2009/10. In early January, when the NAO index switched to positive values, mild air came in from the Atlantic, temperatures rose above normal and

rivers, swollen by rain and melting snow, flooded in Germany, Austria, and Czech Republic.

Spring 2011 was exceptionally warm (more than +3°C), especially during April (Fig. 7.30). Periods of high pressure dominated over central and western Europe to an unusual extent. Several western countries reported their warmest spring in at least 100 years (UK, Netherlands, France, Germany, and Switzerland) or second warmest on record (Luxembourg).

In summer, conditions were more anomalously cyclonic and most areas of central and western Europe experienced near-normal to slightly-above-normal temperatures (Figs. 7.26, 7.27, JJA). However, Ireland and the UK mean temperatures dropped below normal, with anomalies down to -2°C in southwest Ireland.

Autumn seasonal average temperatures were above the 1961–90 normal in all areas of western and central Europe which were all located in the western part of the prevailing high pressure zone (Figs. 7.26, 7.27, SON). November was particularly warm in western Europe, with monthly average records broken in some places. In contrast, southeastern central Europe was colder than average (Fig. 7.31) due to enhanced nocturnal cooling. An autumn mean temperature of 12.2°C made 2011 the warmest autumn in over 150 years in Dublin, Ireland. The UK, France, and Switzerland reported their second warmest autumns for at least 100 years, behind only 2006, with anomalies around +2°C. December was generally mild, but temperatures in northwestern Europe were near normal.

(ii) Precipitation

Central and western Europe had near- to below-normal annual precipitation, except in northern parts of both Ireland and the UK and on the German Baltic coast, where the annual totals locally reached 125% of normal (Fig. 7.28). Scotland experienced its wettest year since at least 1910 and Ireland reported its wettest year since 1986, whereas parts of Slovakia had their driest year since records started in the mid-19th century.

Winter was near normal, except for parts of Ireland, the UK, southern France, and the Alpine region, which were often under anomalous high pressure influence and had precipitation totals of 50–80% of normal (Fig. 7.29, DJF). However, February was wetter than normal in Ireland and most northern parts of the UK due to a more intense and extended area of low pressure (990 hPa) between Southern Greenland and Iceland resulting in increased westerlies.

Spring was dry almost everywhere in the region, except in Scotland (Fig. 7.29, MAM), which was north of the high pressure zone. Germany, the Netherlands, and much of eastern England had their driest spring in more than 100 years, and France experienced its driest in more than 50 years. The dry, warm conditions led to wildfires in early May in the Netherlands, Scotland, Northern Ireland, and parts of England and Wales, and caused significant concern for agriculture and water resources.

In contrast, summer was wetter than normal in most areas due to prevailing cyclonic conditions (Fig. 7.29, JJA). Only Ireland, parts of central England, and southern parts of central Europe had slightly-below-normal precipitation. Ireland reported the driest summer since 2006, while the Netherlands had its wettest since 1906. On 19–22 July thunderstorms with heavy precipitation caused damage in southern and eastern Germany. In Austria, flooding and landslides due to intense thunderstorms on 3–8 August swept four bridges away in Metnitztal, destroyed building roofs in the Innsbruck area, and damaged agricultural crops in Zillertal.

Autumn saw well-below-average precipitation totals (as low as 30% of normal) in many places due to strong high pressure influence, with the exception of northern parts of Ireland and the UK, which were located at the west flank of that blocking high and where up to 170% of normal precipitation was observed. Germany, Austria, the Czech Republic, Slovakia, and Hungary all reported their driest November in more than 100 years, and Luxembourg reported its driest since 1947. In December, some strong cyclonic disturbances reached parts of central Europe, bringing a wet end to the year. A storm passed over western and central Europe on 15–16 December, with gusts of more than 100 km hr^{-1} over France.

(iii) Notable events

Low nighttime temperatures caused damages to vineyards during the first week of May as reported by Austria and Germany, resulting in a 15% drop in income from viticulture.

In Scotland, heavy rain on 11–12 August resulted in floods which disrupted road and rail transport in Glasgow and Edinburgh; this area had experienced persistent wet weather through much of July and early August.

Hurricane Katia moved over the North Atlantic north of Ireland and the UK as a post-tropical storm on 12 September; gusts over 100 km hr^{-1} were re-

corded widely across northern England and southern Scotland.

On 24 October, daily rainfall at the station Dublin Casement Aerodrome in Ireland was 82.2 mm, the greatest daily October rainfall on record at this station since 1954.

On 8 December, a major storm affected Scotland, with winds gusting widely over 130 km hr^{-1}, and up to 250 km hr^{-1} across the mountain summits—the highest gust recorded in the UK since 1996. The storm brought widespread disruption to transport networks and the loss of power to 150 000 homes.

Storm Joachim affected southern France, southern Germany, Switzerland, and Austria on 15–16 December with strong gusts at hurricane force, heavy rain and snow. Gusts reached 183 km hr^{-1} on Zugspitze Mountain in the Alps (Germany). There were many disruptions of road, rail, and air traffic. Most damage was reported from Austria.

3) The Nordic and Baltic Countries—C. Achberger, K. Trachte, A. Obregón, P. Bissolli, and J. J. Kennedy

This region includes Iceland, Norway, Denmark, Sweden, Finland, Estonia, Latvia, and Lithuania.

(i) Temperature

The year 2011 was above the 1961–90 long-term mean in the Nordic and Baltic regions, with anomalies ranging between +1°C and +2.5°C. The highest anomalies were observed in Finland, northern Sweden, and northern Norway (Fig. 7.25). For places in Finland, Sweden, and Norway, 2011 was one of the warmest three years since national records began in 1900 or earlier, despite a cold winter.

Winter temperatures (DJF 2010/11) were 1°C to 2°C colder than normal across large parts of the Nordic and Baltic region (Figs. 7.26, 7.27, DJF); down to 4°C below normal in southern Norway and Sweden. At the end of a cold February after intense arctic air advection, sea ice extent in the Baltic Seas reached 300 000 km^2, the largest since 1987.

Spring temperatures were 0.5°C to 3°C above normal across the whole region (Figs. 7.26, 7.27, MAM), since northern Europe was much affected by the extended high pressure zone. April was an exceptionally warm month, with monthly mean temperature records set in all Nordic countries.

Temperatures were 1°C to 3°C above normal across the region in summer (Figs. 7.26, 7.27, JJA). The east European blocking high and warm air advection extended far north to Scandinavia. Finland experienced its fourth warmest summer while Iceland and Denmark summer temperatures were close to normal. Latvia experienced its warmest June–July period in the past 88 years.

Autumn temperatures continued to be above normal (Figs. 7.26, 7.27, SON), with anomalies of around +1°C in southern Denmark and Lithuania, and exceeding 5°C farther north. Again, high pressure influence extended far to the north. Norway and northern parts of Sweden reported their warmest autumn since 1900. December 2011 was much warmer than normal in Finland (by more than +7°C), Sweden, and the Baltic States, since mild Atlantic air masses often crossed southern parts of northern Europe when moving to the east.

(ii) Precipitation

Mean annual precipitation conditions were close to normal in most of the Nordic and Baltic regions. However, Norway experienced its wettest year since 1900, with a national average of 130% of normal. Similar anomalies were observed locally in Sweden. The Baltic countries and western Iceland were drier, with 60–80% of normal precipitation totals in some areas (Fig. 7.28).

Winter precipitation was lower than normal in most of the Nordic countries, reflecting prevailing anticyclonic conditions in the north, although there were strong local deviations (Fig. 7.29, DJF). However, in spite of relatively low precipitation totals (Norway received 30–50% of normal), the snow season started early due to low temperatures and considerable snow depths developed during the winter and early spring. The Baltic States, which were located near the mean center of low geopotential height (Fig. 7.27) had precipitation totals that were 110–130% of normal; the primary form of precipitation was snow.

Spring was wet, with 130–150% of normal precipitation in Sweden and Norway (Fig. 7.29, MAM). Low pressure systems were deflected north of the large European high pressure system. The largest anomalies (up to 300%) were in central Norway and the west Norwegian coast. Denmark and the Baltic countries were located within the anticyclonic area and had a dry spring (20% of normal); March and April in particular were very dry (20–40% of normal).

Summer 2011 was also a wet season in many parts of the region (130–170% of the normal; Fig. 7.29, JJA). Norway and Denmark, which were especially influenced by cyclonic conditions, experienced their second wettest summer since at least 1900. A large fraction of the summer precipitation came as heavy rainfall events. In contrast, most of Iceland was fre-

quently under high pressure conditions and had only 30–50% of normal precipitation.

Autumn precipitation amounts varied considerably, from 130–170% of normal in southern and northern Norway and northern Sweden, which were north of the high pressure zone, to 30–70% in Denmark and the Baltic States (Fig. 7.29, SON), which were within. November was a dry month in southern parts, but was followed by a wet December with frequent low pressure systems in most of the region (the wettest on record in Latvia).

(iii) Notable events

On 24 March, Finland reported heavy snow showers and strong wind gusts that caused a sudden drop in visibility to near zero. Seventy cars were damaged and several dozen people injured.

An unusually wide ranging Saharan Dust transport from Africa to Scandinavia occurred in early April.

Northern and northeastern Iceland were hit by an unseasonal snow storm on 23–24 May.

From 8 to 13 June, flooding occurred in Norway due to torrential rainfall with melting snow. The result was devastating floods that washed away several houses and roads and caused landslides.

On 24 July, thunderstorms brought heavy precipitation across Finland and a daily precipitation total of 121 mm in Tornio. Flooding in the capital Helsinki on 22 August was caused by a line of thunderstorms from the Gulf of Finland.

On 25 and 26 December, Norway, Sweden, and southern and western parts of Finland were hit by high wind speeds in the severe winter storm Dagmar (up to 113 km hr^{-1} in Finland), which was the most damaging winter storm since 2001, causing widespread electricity disruptions. In middle and northern Sweden, trains were halted and roads were temporarily closed. Also in December, the national monthly precipitation record was broken in Kemiönsaari in southern Finland with 190 mm, three times the December monthly average.

4) Iberia—K. Trachte, A. Obregón, P. Bissolli, R. Trigo, D. Barriopedro, C. Gouveia, and D. E. Parker

This region includes Portugal and Spain.

(i) Temperature

The Iberian Peninsula was warmer than normal, with annual positive anomalies of +1°C to +2°C in most regions (Fig. 7.25), except in the southwest, where anomalies were 0°C to +1°C. Spain observed its warmest year since 1961, while Portugal had its annually-averaged maximum temperature among the three warmest since 1931.

The winter season 2010/11 was mostly slightly above normal with 0°C to +1°C anomalies (Figs. 7.26, 7.27, DJF). Spring was warmer than normal (+2°C to +3°C throughout the Iberian Peninsula), except the southern coastal region, which had anomalies of +1°C to +2°C (Figs. 7.26, 7.27, MAM). It was the warmest spring since at least 1951 in Spain and the second warmest in Portugal since 1931. April and May were particularly warm, consistent with the dominance of strong anticyclonic conditions over western Europe (Fig. 7.26); the mean April temperature anomaly in Iberia reached +3.9°C, the highest value observed since 1951.

Summer was warmer than normal in southeastern Iberia (related to higher-than-normal geopotential) and near normal in the northwest (Figs. 7.26, 7.27, JJA). June and August were very warm, especially in southern and eastern Spain, with the spatially-averaged anomalies reaching +1.5°C and +1.4°C, respectively.

Autumn was much warmer than normal due to prevailing anticyclonic conditions in most areas in all three months (Figs. 7.26, 7.27, SON), the third warmest autumn in Portugal and Spain since 1931 and 1960, respectively. Both countries reported a mean anomaly above +2°C in October. December was near normal in the west, but still well above normal in the east.

(ii) Precipitation

Annual precipitation was below normal throughout the Iberian Peninsula (Fig. 7.28). Average rainfall in Spain was 565 mm (87% of the 1971–2000 normal) and 750 mm in Portugal (85% of the 1971–2000 normal), mainly due to rainfall deficits during summer and the first part of autumn.

Winter 2010/11 saw far more cyclonic situations than usual and was especially wet in southern parts of Spain, at more than 150% of normal, whereas eastern areas were very dry. Despite the dry January (50–70% of normal), Portugal was relatively wet on average (Fig. 7.29, DJF), in agreement with a dominant negative NAO seasonal index (-1.0).

In northern Iberia, spring was dry whereas the rest of the peninsula experienced above-normal precipitation totals (Fig. 7.29, MAM), due to prevailing cyclonic conditions in southern Europe. In Spain, March was wetter than normal (around 150% of the spatially-averaged normal), while April and May

were near normal. Southern Portugal experienced 150–200% of its 1971–2000 precipitation average in April and May.

Summer was drier than usual throughout the Iberian Peninsula; there was not much cyclonic activity (Fig. 7.29, JJA). Spain had only around 70% of normal precipitation.

Autumn precipitation in Iberia was slightly below normal (Fig. 7.29, SON), while the first half of autumn was exceptionally dry in Spain with prevailing anticyclonic conditions. September was Spain's driest month for 2011, and its driest September since 1988, with a monthly average of only 15 mm rainfall—a third of normal. September was also dry in Portugal with 50–75% of normal, although some areas of Portugal had precipitation totals that were 250% of normal. The zonal dipole of Fig. 7.27 with negative autumn height anomalies over the eastern Atlantic was more pronounced in November, and all areas in Portugal and most of Spain had above-normal precipitation, at 125–150% of normal.

In December, the situation reversed. The Azores high became very strong and both Spain and Portugal experienced very dry conditions. Spain recorded precipitation totals (25 mm) of only 30% of the spatially-averaged mean (82 mm). Portugal also received much-below-average rainfall, with as little as 25% of normal in the south.

(iii) Notable events

On 16 February, a storm with heavy rainfall, snowfall and wind gusts exceeding 100 km hr^{-1} hit the western coast of the Iberian Peninsula, destroying roofs and downing trees.

The warm months of April and May in Portugal were associated with three heat waves, including several tropical nights (i.e., minimum temperature above 20°C). Between the periods of heat waves, heavy rainfall occurred on 29 April and flash floods with heavy sleet and hail affected the region of Lisbon.

The first half of October in Spain was the hottest since at least 1961, with temperature anomalies ranging between +3°C and +4°C and maximum daily temperatures climbing up to 6°C above their normal values. Numerous stations in northern, central, and southern Spain exceeded 30°C and set new historical daily records for October. This month was also very warm in Portugal, which was affected by two heat waves between the latter part of September and the end of October. The extreme hot weather triggered an unusually high number of fires in October in northwestern Iberia. However, during 23–27 October, extreme rainfalls (up to 117.5 mm in 24 hours) affected northwestern Spain.

5) Mediterranean, Italian, and Balkan Peninsulas

—K. Trachte, A. Obregón, P. Bissolli, S. Sensoy, and D. Parker

This region includes Italy, Malta, Slovenia, Croatia, Serbia, Montenegro, Bosnia and Herzegovina, Albania, Macedonia, Greece, Bulgaria, and Turkey.

(i) Temperature

Mean annual temperatures over the western Mediterranean region and in southeastern Europe were generally above the 1961–90 average. Annual temperature anomalies were mostly +1°C to +2°C, although the eastern Balkan Peninsula and the eastern Mediterranean had temperatures near normal (Fig. 7.25), and the northern part of Turkey was slightly cooler than normal.

Temperatures during winter 2010/11 were near normal in most areas but more than +1°C above average over the eastern Mediterranean and Turkey (Figs. 7.26, 7.27, DJF), and more than +2°C in eastern Turkey, due to warm air advection. Parts of the Balkan Peninsula had slightly negative anomalies, particularly eastern parts. February was especially cold over most of the Balkan Peninsula, when cold Arctic air advanced far to the south .

During spring, anomalous warmth affected the western Mediterranean due to extended anticyclonic conditions, with anomalies of up to +2°C to +3°C in northern Italy and Slovenia (Fig. 7.29, MAM); April was especially warm. Conversely, most of Bulgaria, Greece, and Turkey experienced below-average temperatures in spring with anomalies at 0°C to -1°C due to cold air advection east of the high pressure zone; localized areas in Turkey observed even cooler anomalies.

Summer temperatures were above normal in most of the area (Fig. 7.29, JJA) due to warm air advection from the southeast. The western Balkan Peninsula experienced particular warmth, with +1°C to +3°C anomalies.

Autumn temperatures were above normal over the western Mediterranean basin due to extended anticyclonic conditions, whereas the eastern region experienced mostly below-average temperatures due to cold air advection from the north (Fig. 7.29, SON). August and September were extremely warm in Italy and on the Balkan Peninsula; October and November were cold in the east. Bulgaria and Turkey reported November monthly anomalies of -2.7°C, and -3.2°C, respectively, making it the coldest month of 2011

(Fig. 7.31). In December, most of Italy and the Balkan Peninsula experienced mild air advection with above-average temperatures, especially in northern parts, with anomalies above +2°C in northwestern Croatia and northern Serbia.

(ii) Precipitation

The year 2011 had less precipitation than normal in northern Italy and most areas of the Balkan Peninsula (Fig. 7.28). Precipitation totals were only 60–80% of normal and in some areas in Slovenia and eastern Croatia even lower. Much-above-average precipitation occurred only over Sicily, which had more than 125% of normal.

Winter precipitation totals were 70–90% of average in Italy and the coastal regions of the Balkan Peninsula (Fig. 7.29, DJF). There was more cyclonic activity in the western Mediterranean basin compared to the east. In northwestern Italy and Sicily, above-normal precipitation amounts were observed. Croatia and Greece reported dry-to-normal conditions, despite the sporadic occurrence of high precipitation events in Greece in January.

With increasing anticyclonicity, the precipitation deficit extended into spring on the Balkan Peninsula and in the northern Mediterranean Sea areas (Fig. 7.29, MAM). However, cyclonic conditions developed over the southern and eastern Mediterranean. Southern Italy and Greece, as well as Turkey (especially its coastal areas) received above-normal precipitation. Sicily reported up to 170% of normal.

In almost all parts of Italy and the Balkan Peninsula, anticyclonic conditions were prevailing and below-average precipitation totals were reported in summer (Fig. 7.29, JJA) and autumn (Fig. 7.29, SON), despite some heavy thunderstorms, whereas most parts of Turkey had higher-than-normal summer precipitation due to a high convective activity. The Adriatic countries experienced as little as 30–50% of the normal autumn precipitation. September was the driest month for Bulgaria, especially in the north. Serbia experienced very dry conditions, especially in November with nationally-averaged precipitation totals of less than 25% of normal. There was 50% below-normal precipitation in Turkey when NAO index was positive in November. (There is a negative relationship between NAO index and Turkey's precipitation.)

In December, when westerlies reached central and parts of southeastern Europe, the rainfall was normal or higher on the Balkan Peninsula, while Italy and eastern Turkey continued to see deficits.

(iii) Notable events

On 23 February, a dust storm, which formed west of the Nile delta spread northwards to Crete island (Greece).

In March, a Mediterranean depression brought heavy rainfall, bora (i.e., strong north-to-northeasterly downslope winds at the east coast of the Adriatic Sea), and snowfall to southeastern Europe and Italy. In Greece, a landslide occurred due to heavy rain; and snowfalls on the Peloponnese, in the south, were reported during 8–10 March. In contrast, due to the very dry April, forest fires occurred in Bulgaria on 9 and 30 April.

Dust was transported northward from the North African coast off Egypt and Libya over the Mediterranean Sea on 16 April.

During a hailstorm, which occurred in Ankara on 16 June, the accumulated hail depth reached 20 cm. Some underpass exits were flooded or blocked by hail and traffic was disrupted. Hundreds of cars were damaged by the hail.

On 24–25 August a storm with egg-sized hail caused damage in western and central Bulgaria, and a long dry period from 13 to 30 August caused damage to agriculture.

During 8–17 October, Greece, Bulgaria, and Turkey had extremely heavy rainfall. Turkey reported its highest daily total in October of 300.4 mm in Antalya. (The record high daily total was 332 mm, set in January 1969.) October rainfall (395.8 mm) was 483% of normal (82 mm). In Shabla, eastern Bulgaria, due to a vigorous storm during 16–18 October, 156.5 mm precipitation within 24 hours was measured, around four times the monthly normal.

Extremely heavy rain on 21 October brought Dubrovnik, Croatia, a daily total of 185.5 mm, nearly twice the monthly normal. During 23–27 October, the Ligurian coast of northern Italy had extreme precipitation totals due to an intense storm system that caused mud and debris slides. Cyclone Rolf hit northwestern Italy during 3–8 November, with high rainfall intensities, producing a 454-mm daily total on 4 November in Vicomorassa, north of Genoa.

In Slovenia on 4 October, record-breaking October maximum temperatures of 29.8°C in Bilje and 25.9°C in Postojna were observed.

6) Eastern Europe—K. Trachte, A. Obregón, P. Bissolli, and D. E. Parker

This region includes European Russia, Belarus, Ukraine, Moldova, and Romania.

(i) Temperature

Eastern Europe was mainly warmer than normal during 2011, especially in the north where the year was +1°C to +2°C above the 1961–90 average (Fig. 7.25). Ukraine and Romania reported positive anomalies of +1°C and +0.4°C, respectively.

The winter season was colder than average, with negative anomalies below -4°C in northwestern Russia (Figs. 7.26, 7.27, DJF). Only southern parts of European Russia were warmer than normal on the seasonal average. February was especially cold throughout eastern Europe, when cold arctic air was advected. In the Ukraine, positive anomalies of +2°C to +3°C in January were followed by anomalies of -1.5°C to -2.5°C in February. The absolute minimum air temperature of 2011 of -31°C in the Ukraine was measured in February in the Luhansk region (not a record). Romania also reported a below-normal anomaly of -1.2°C in February.

During spring (Figs. 7.26, 7.27, MAM), there were positive anomalies in the anticyclonically influenced western part of the Ukraine and Belarus with +1°C to +2 °C and in northern European Russia up to +4°C, but southeastern areas, which were still under prevailing cold air advection had slightly below-average temperatures.

The summer season brought particularly high positive anomalies over eastern Europe due to an extended blocking high. Western Russia experienced positive anomalies of +3°C to +4°C and Belarus observed +2°C to +3 °C (Figs. 7.26, 7.27, JJA). It was the third warmest summer on record in Moscow, but far less extreme than in 2010. July had particularly high anomalies, up to more than +4°C, over large parts of western Russia. In the Ukraine, too, July was the warmest summer month with the highest monthly anomalies of summer 2011, and a monthly mean temperature of 19°C – 25°C. Romania reported anomalies of +2°C to +3°C in August for its western and mountain areas.

In the northern part of eastern Europe, the warmth continued into autumn (Figs. 7.26, 7.27, SON). Romania reported an anomaly of +2.6°C in September and more than +4°C in southwestern areas. In southwestern Russia, cold air advection developed and below-average temperature anomalies of 0°C to -1°C were observed in the same month. In December, westerlies crossed Europe to the east, and all areas in eastern Europe experienced well-above normal temperatures, with anomalies of more than +4°C in most of European Russia, the northern Ukraine, and Belarus.

(ii) Precipitation

Precipitation totals in 2011 were generally around normal in eastern Europe. Only western Ukraine, Moldova, and western Romania had below-normal precipitation totals of 60–80% (Fig. 7.28). Some areas in western and southern regions of European Russia had totals of more than 125% of normal.

Winter had near-normal precipitation amounts, except for some areas in western and central European Russia, which had 110–130% of the long-term mean; southern parts of European Russia were dry (Fig. 7.29, DJF). There was a notable precipitation deficit during February in most of eastern Europe because of prevailing cold and dry air.

During spring, the Ukraine, Belarus, and parts of Russia were very dry under high pressure influence (Fig. 7.29, MAM). In March, much of the western parts of eastern Europe received only around 40% of normal precipitation.

During summer, the western areas of eastern Europe were cyclonically influenced and received above-normal precipitation totals while the eastern areas had anticyclonic conditions and below-average values. The Ukraine had its maximum precipitation anomalies in June and July, at 100–150% of normal. Central and southern regions of the country received persistent heavy rainfalls with 145 mm – 195 mm in the last 10 days of June, which is 250–350% of normal. In Romania, June and July precipitation was 112% and 129% of normal, respectively. In contrast, August had long periods of rainless weather in large parts of eastern Europe.

Autumn was dominated by anticyclonic conditions and much-below-average precipitation in the western areas of eastern Europe (Fig. 7.29, SON). The Ukraine, Moldova, and Romania each reported a large precipitation deficit with totals of 30–50% of the seasonal normal with greatest deficits in September. These deficits partly continued in December; in contrast, European Russia was mostly wet due to frequent low pressure systems, except in the south.

7) Middle East—A. Hovsepyan, V. Grigoryan, K. Trachte, A. Obregón, P. Bissolli, and D. E. Parker

This region includes Israel, Cyprus, Jordan, Lebanon, Syria, western Kazakhstan, Armenia, Georgia, and Azerbaijan.

(i) Temperature

The Middle East as a whole in 2011 had a near-normal annually-averaged temperature, but it was mostly 0.5°C to 1°C below average in western parts of the South Caucasus (Armenia, Azerbaijan, Georgia; Fig. 7.25).

Winter 2010/11 had mostly anticyclonic conditions and higher-than-average temperatures throughout the region, mostly by more than 1°C (Figs. 7.26, 7.27, DJF). The South Caucasus reported seasonal anomalies up to +5°C. February temperatures were much below normal in west Kazakhstan (-3°C to -4°C anomaly), due to cold air advection from the north, and slightly below normal south of the Caucasus.

In spring, temperatures in west Kazakhstan, Georgia, and eastern Azerbaijan were slightly below average due to cold air advection, but near-to-slightly-above normal in Armenia, western Azerbaijan, and in southern parts of the Middle East (Figs. 7.26, 7.27, MAM). Warmer-than-average conditions (around +1°C anomaly) dominated throughout the Middle East during the summer season (Figs. 7.26, 7.27, JJA) due to warm air advection from the south. Several countries reported record high maximum daily air temperatures. Armenia experienced an all-time national record of 43.7°C on 31 July. Azerbaijan recorded 44.7°C (a new local record) on 31 July, and in the last week of July, temperatures reached 44.3°C in Israel, 46.5°C in Jordan, and 45°C in Syria.

Autumn began with above- or near-normal temperatures in September, and ended with a cold November, with anomalies around -1°C in Cyprus and below -4°C in parts of west Kazakhstan and the South Caucasus (Figs. 7.26, 7.27, SON), when cold air was advected east of a strong high over eastern central Europe. Armenia had its coolest November since 1966, with anomalies reaching as low as -6°C; new monthly minimum temperature records were set for certain locations (e.g., -29°C in northern Armenia). December was still slightly cooler than normal or near normal in most areas of the Middle East.

(ii) Precipitation

Annual precipitation totals were mostly near average in the Middle East (70–130% of the normal), with some local wet and dry anomalies (Fig. 7.28).

The winter season in the South Caucasus brought particularly high precipitation totals in February, with up to more than 400% of normal in western Georgia, about 350% in eastern Georgia, and up to 240–300% of normal in the Lake Sevan basin in Armenia (Fig. 7.29, DJF), when a broad upper-level trough extended far to the south. Cyprus remained under high pressure influence and reported mainly below-average precipitation totals in winter 2010/11.

The southeastern Middle East was mostly under high pressure influence and experienced a very dry spring in 2011, while other parts of the region were wetter than normal (Fig. 7.29, MAM) due to prevailing cyclonic conditions. Eastern Syria and Jordan had an extremely dry March and May.

Summer was dry over the entire South Caucasus region and West Kazakhstan due to the large blocking high over eastern Europe. Dry conditions, especially in June and July, led to drought in Ararat Valley and Syunik Valley in the south of Armenia (Fig. 7.29, JJA). Autumn had very localized anomalies inland but mostly above-normal precipitation in both the Mediterranean and Black Sea coastal areas and in west Kazakhstan (Fig. 7.29, SON) due to occasional cyclonic activity. In contrast, December was dry in the Middle East and in the South Caucasus region; these areas were influenced by an extended Russian high.

(iii) Notable events

The year 2011 was remarkable due to the frequent occurrence of weather hazards and climate extremes, particularly for the South Caucasus.

On 23 January, a flood damaged energy systems in western Georgia, and a tornado was recorded in the northeast of Geri area, Cyprus. Strong winds were recorded often during the winter months in the South Caucasus. In particular, in February in Absheron peninsula, Azerbaijan, the wind speed reached 72 km hr^{-1} – 100 km hr^{-1}, with gusts up to 104 km hr^{-1}. Due to a significant pressure gradient at high altitudes, a strong wind was reported in February in Pushkin pass, with the maximum velocity reaching 115 km hr^{-1} and gusts of 165 km hr^{-1}.

In Armenia, heavy snowfall was recorded in March, and flooding due to heavy precipitation amounts occurred in Kazakhstan during 1–19 April. On 12 April, more heavy snowfall was reported from northern Armenia; on 20 April, "yellow" snowfall (snow with sand/dust from the Arabian deserts) occurred in Gyumri city, Armenia.

SIDEBAR 7.3: DROUGHT AND PRECIPITATION EXTREMES IN EUROPE—J. J. KENNEDY, M. KENDON, K. TRACHTE, A. OBREGÓN, P. BISSOLLI, R. TRIGO, D. BARRIOPEDRO, AND C. GOUVEIA

Spring and autumn 2011 exhibited a sharped spatial gradient in precipitation across Europe. While large midlatitude areas of western, central, and even parts of eastern and southern Europe were dominated by a long-lasting dry period in the two transition seasons, the northernmost and southernmost regions of Europe received outstandingly abundant precipitation. Seasonal precipitation totals amounted to 40–80% of normal (1961–90 base period) in the dry areas and 130–170% in some of the wet regions (Fig. 7.29). The driest areas were in western Europe in spring, and further east in autumn (Fig. 7.29). In some places, the precipitation anomalies observed during autumn and spring extended into the winter and summer months, respectively, resulting in a similar precipitation pattern for the whole of 2011 (Fig. 7.28), though it was less pronounced in central Europe due to a wet summer.

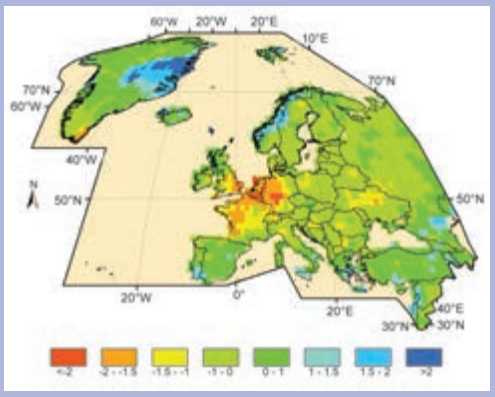

Fig. SB7.4. Standardized Precipitation Index (modified from Pietzsch and Bissolli 2011; deviation from 1961–90 base period) for spring 2011. (Source: Deutscher Wetterdienst)

The situation was particularly evident in the UK, where most of southern, central, and eastern England experienced both an exceptionally dry spring and a very dry autumn. As a result, much of central and eastern England received around 75%, or less, of the annual average rainfall for 2011 overall, and less than 65% in some places. Several counties had their driest year since at least 1910. The dryness may be traced back to December 2009—with 20 out of the 25 months since then seeing below-average rainfall. In contrast, Scotland had its wettest year since national records began in 1910 (it should be noted that some individual station records date back further), with much of southern and central Scotland receiving well over 125% of average.

Other areas in western and central Europe had a very dry spring and autumn, but with a rainy summer in between the two seasons. Western Germany, the Netherlands, Belgium, Luxembourg, and northern France experienced an extremely dry spring, similar to exceptional droughts in 1976 and the 1990s (Fig. SB7.4). Germany had its driest spring since 1893 and the Netherlands had its driest in at least a century, with an average precipitation total of 49 mm (28% of normal) and a potential precipitation deficit exceeding the previous record of 1976 until end of May. France recorded its driest spring in 50 years, with precipitation totals that were 46% of normal. This anomalous situation in spring was accompanied by an unusual recurrence of blocking patterns over the midlatitudes of central Europe, whose centers of action were shifted southward of their usually preferred high-latitude regions (Fig. SB7.5a).

The dryness in England and the wet conditions in Scotland made 2011 a difficult year for agriculture in both areas. There were also wide concerns on water resources in general; drought conditions were declared across parts of eastern England in early summer. The spring drought in central and western Europe created ideal conditions for large wildfires (e.g., those seen in Ireland and coastal parts of the Netherlands). In Germany, Austria, and Hungary, shipping was affected, due to low water levels on the Rhine and Danube Rivers. In May, levels reached their lowest point in a century.

In contrast, the Mediterranean region received well-above-normal precipitation in spring, due to several extreme rainfall events. On 1–2 March, a Mediterranean depression with heavy precipitation affected Italy and Slovenia. In Matera, Basiskata (Italy), 129 mm of rain fell in 24 hours. In Sicily, totals of

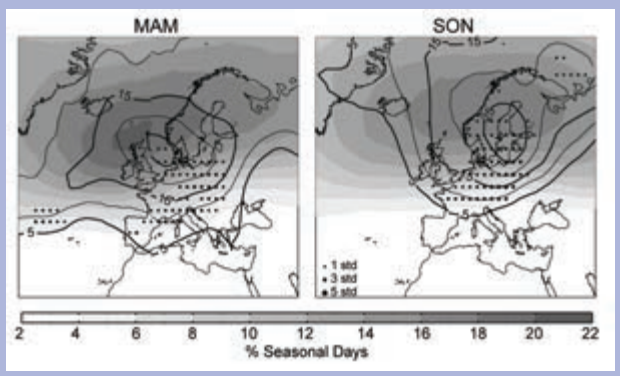

Fig. SB7.5. Seasonal blocking frequency (% seasonal days, i.e., 1% corresponds to ~1 day per season) in (a) MAM and (b) SON. Shaded areas denote the 1948–2010 mean blocking frequency. Black thick lines indicate the seasonal blocking activity in 2011. Dots highlight those areas where the seasonal frequency of blocking patterns was above the 90th percentile of the 1948–2010 distribution, with the size of the dot being proportional to the exceedance over the climatological mean in standard units (i.e., the standardized anomaly). Blocking patterns are identified following the method described in Barriopedro et al. (2010). (Source: NCEP/NCAR reanalysis)

117 mm in Messina and 109 mm in Palermo were recorded. On 8–10 March snowfalls in southern Greece and on 9 March heavy snowfalls in Armenia were reported. In southern France, 400 mm – 500 mm precipitation totals fell during 12–16 March. In Novi Pazar, in southwest Serbia, torrential rainfall on 23 May caused flooding that damaged about 500 houses.

Autumn 2011 was dominated by unusual warmth and long-lasting dry periods in most countries of Europe, resulting from anomalously high blocking activity over central and northeastern Europe (Fig. SB7.5b). Extremely dry conditions occurred in central, eastern, and southeastern European countries.

November was especially dry (Fig. SB7.6), with record-breaking precipitation deficits in many countries. In Germany and Austria, the lack of precipitation affected shipping on rivers. It was the driest November in Germany since records began in 1881, as well as for the Netherlands and Slovakia. Hungary and Moldova reported only 1 mm – 3 mm of precipitation for around 75% of the country, only 2–7% of normal. The Czech Republic reported less than 2% of the normal monthly precipitation across most areas, and Prague had its driest November in its 206-year period of record.

The autumn drought enabled fires in Austria, Romania, and Bulgaria. Damage to forests in Bulgaria was estimated at around $2.4 million (US dollars). Similarly, the dry and hot autumn months over western Iberia also provided optimum conditions for an unusually high number of fires in October. In contrast, heavy precipitation occurred in other places of southern Europe (e.g., more than 400 mm fell in six hours at the famous Cinque Terre area of the Ligurian coast in northwestern Italy on 25 October). A Mediterranean storm hit coastal areas of southern France on 1–9 November with gusts up to 150 km hr^{-1} and torrential rain, locally up to 800 mm, over this period (Fig. SB7.7). In Italy, the same storm caused flooding around Genoa when rainfall totals reached 400 mm in 12 hours on 4 November. The Po River rose by four meters in Turin. This storm was classified as a Mediterranean "tropical storm" by NOAA because of its tropical characteristics, the first ever issued for the Mediterranean.

Persistent high pressure over western and central Europe was responsible for this pronounced climate pattern of dry conditions in these areas and high precipitation north and south of it in both spring and autumn (Figs. 7.29; SB7.7). Despite positive NAO values from February to April and September to December (http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml), the blocking high prevented low pressure systems from reaching continental Europe. Instead they were deflected to northern and southern parts of Europe leading to above-normal precipitation totals, following the typical mechanism during these blocking high patterns (Trigo et al. 2004). The surface pressure distribution was similar in spring and autumn, but pressure was highest towards western Europe in spring, whereas in autumn the center was located over eastern central Europe, exceeding 1025 hPa over the Balkan Peninsula and the western Black Sea area in November. A strongly developed low over Scandinavia at the end of November finally broke the drought situation in central Europe.

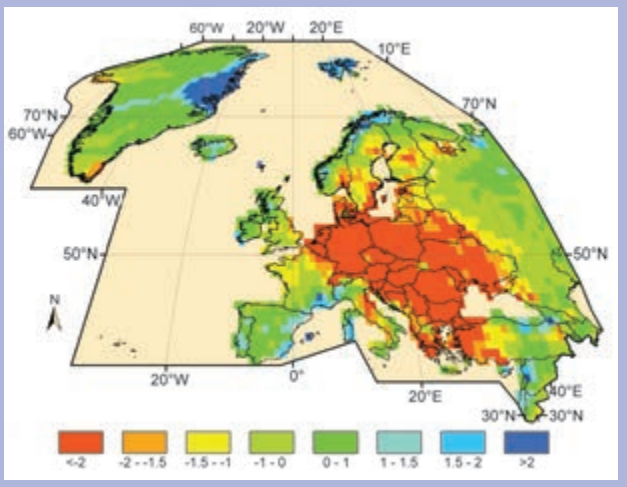

Fig. SB7.6. Standardized Precipitation Index (modified from Pietzsch and Bissolli 2011; departure from 1961–90 base period) for November 2011. (Source: Deutscher Wetterdienst)

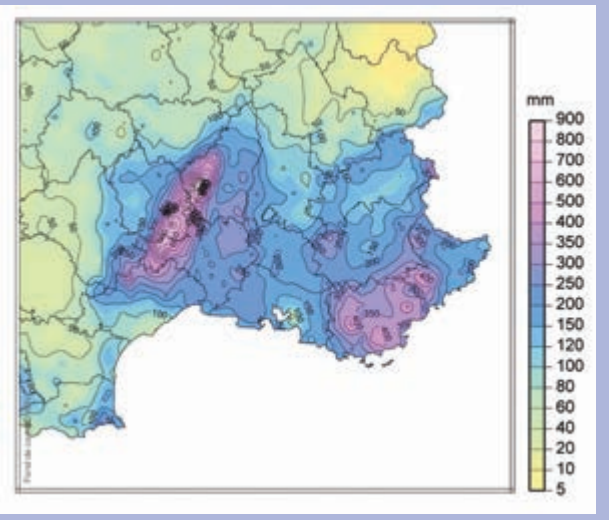

Fig. SB7.7. Accumulated precipitation (mm) for the period 1–9 Nov 2011 in southeast France. (Source: Météo France)

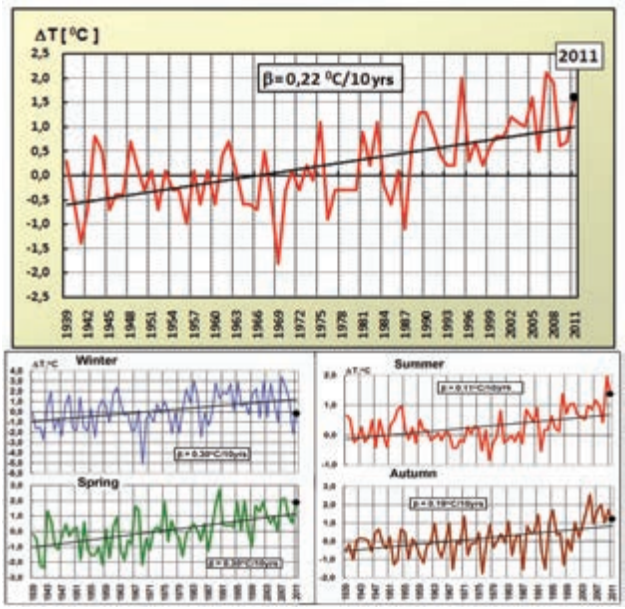

Fig. 7.32. Annual and seasonal mean temperature anomalies (°C) averaged over the Russian Federation.

Thunderstorms with severe hail and rainfall were reported from May to August in the South Caucasus. Seventeen days with hail were reported in different locations of Armenia, with hailstones sometimes reaching 25 mm in diameter. Hail caused loss to agriculture, damaging crops. During 24–27 May, heavy rainfall in the eastern part of Georgia was followed by flash floods that inundated houses. In early June, floods damaged houses and crops in eastern Georgia. From 18 to 19 June, seven people died due to a landslide on Rikoti Pass, which destroyed several buildings. Another heavy rainfall was reported on 7 July in the Vanadzor town in northern Armenia with an intensity of 37 mm in 40 minutes; on 18 August, in Aparan, Armenia, 51 mm of rain fell in 40 minutes. And on 3 October, a massive landslide occurred in northern Armenia near the Georgia border after a heavy rainfall: 35 vehicles were buried, seven people were injured, and five people were killed.

On 26 September, a severe hailstorm in the areas of Amiantos and Kiperounta in Cyprus damaged fruit trees, and a tornado on 12 November affected the Cyprian holiday villages of Mazotos and Anafotia.

g. Asia

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

(i) Temperature

By and large, 2011 was a warm year in Russia. The mean annual temperature anomaly averaged over the Russian territory was +1.55°C (Fig. 7.32). Along with 2005, this anomaly ranks as fourth or fifth warmest since 1939. Temperature anomalies averaged over the Russian territory were positive for all seasons, except for winter (DJF) which was close to normal (0.15°C below average).

January 2011 was warmer than the long-term average overall. Maximum positive temperature anomalies of 9°C – 10°C, were recorded in northwestern Yakutia. In the south of Western Siberia, however, a large cold island formed, at the center of which mean monthly temperature anomalies reached -9°C. In the first ten-day period, air temperatures dropped as low as -35°C to -44°C in the south of the region. The largest negative temperature anomalies were recorded in the Minusinsk basin (-9.4°C), where the air under winter anticyclone cools significantly at night. In the third ten-day period, minimum temperatures dropped to -48°C in Transbaikalia.

February was the only month during 2011 when mean temperatures were below the long-term average. Northern European Russia experienced the cold island, at the center of which the negative anomalies of monthly mean temperature were greater than -8°C. Night temperatures dropped to -42°C to -46°C, associated with an intense anticyclone that spread over northern European Russia from the Kara Sea. In the second ten-day period, St. Petersburg experienced record-breaking cold for the entire period. In the latter half of February, cold weather spread to Central Volga and Ural. On the last day of winter, new record-breaking temperature minima were registered in the Volga Region: -31.6°C in Ulyanovsk, -29.0°C in Izhevsk, and -30.5°C in Samara.

Spring over the Russian territory as a whole was much warmer than the long-term average, with a mean seasonal temperature anomaly of +1.91°C (Fig. 7.32). This anomaly is largely connected with very warm March and April temperatures in the north of the country.

Most of Russia was warm during spring. Maximum positive anomalies of mean monthly air temperatures were recorded on the Arctic coast of the Yamalo-Nenets Autonomous District (9°C – 12°C) and Taimyr (8°C – 10°C). During the last days of March, the temperature was more than 20°C above normal. Another large warm island formed over northeastern Yakutia and continental areas of the Magadan Region, where mean monthly temperatures were 9°C – 10°C above normal.

The distribution of mean monthly temperature anomalies in April was similar to March, with temperatures in northern regions considerably higher than those in southern regions. The warm island,

with temperature anomalies at its center greater than 7°C – 8°C, formed above the eastern Yamalo-Nenets Autonomous District. Warm weather settled unusually early in the south of Western Siberia; new temperature records were established in a number of cities. This was associated with southwesterlies that brought warm air from Central Asia. May was also warmer than the long-term average. The average surface temperature anomaly for summer 2011 was +1.40°C (Fig. 7.32), which ranked third for the period of observation, following the record-breaking year 2010 (+1.78°C) and 1998 (+1.45°C). The two vast warm areas with anomalies to +3.9°C in central European Russia and to +2.9°C in Yakutia occupied a large part of the Russian area. The area with small negative temperature anomalies (to -0.5°C) was situated in the Western Siberian Lowland, between the two warm areas.

In June, particularly warm weather was recorded in the Yamal-Nenets Autonomous District, where mean monthly air temperature anomalies reached 5°C – 6°C in the southeast of the District. Abnormally warm weather persisted throughout the first ten-day period in the Yamal-Nenets Autonomous District and central Krasnoyarsk Territory, with mean daily air temperatures being 10°C – 24°C above normal in this period. Hot weather in both early and late June was recorded in central European Russia and the Volga Region.

During the first ten-day period of July in mid-Volga and Lower Volga, daytime temperatures rose to 40°C – 43°C. Southeasterlies brought dry and hot air from the Kazakhstan steppes to mid-Volga. New temperature records were established.

In early August, Dagestan was the warmest area in Europe, as a result of hot air coming from Iran and Turkey. The second ten-day period was hottest in the Volga and Central Chernozem Regions, where temperatures reached 35°C – 39°C. The Upper Volga experienced abnormally warm weather in mid-August, when daytime temperatures rose to 35°C – 37°C. In Western Siberia, with the exception of deep southern regions and the Arctic coast of Yamal, mean monthly temperatures were below normal for two months running (July and August).

Fall temperatures were above normal across Russia, except in Northern Caucasia. September was mostly warmer than the long-term average. The first ten-day period of September was as warm as summer in the Southern Urals. At the end of September, mean daily temperatures in northern Western Siberia were 8°C – 10°C above normal.

For October, the mean monthly temperature averaged over the whole of Russia ranked third warmest since 1939. In central European Russia, western Siberia, and eastern Siberia the first ten-day period was nearly as warm as summer. Temperature records were broken in many centrally-located cities and Upper Volga. In mid-October, daily temperature maxima were observed in southern European Russia and southern Western Siberia. New daily temperature records were established. On 11 October, a new daily temperature record was established in Krasnodar (30.2°C), and on 15 October Novosibirsk set a new daily record maximum temperature(20.2°C).

A positive temperature anomaly averaged over all of Russia was recorded in November. November mean monthly temperatures were above normal over most of the Yamalo-Nenets Autonomous District, Tomsk Region, and Altai Republic. At the Arctic coast of Yamal, the temperature anomaly was more than +6°C. Maximum temperature anomalies of +7°C to +9°C were recorded on Taimyr and Arctic islands. In southern European Russia, however, November was much colder than average, with mean monthly air temperature anomalies between -4°C and -6°C. Night temperatures dropped to as low as -15°C to -20°C, breaking minimum temperature records in a number of cities (e.g., Volgograd, Vladikavkaz, and Makhachkala). Clear nights with anticyclonic conditions contributed to extreme land surface cooling and, as a result, record-breaking low temperatures in central European Russia, with previous records being exceeded by 4°C to 5°C in many cities.

In December, an intense heat island formed over the Arctic coast and islands in Western Siberia and European Russia, with the highest mean monthly temperature anomalies (+12°C to +14°C) recorded. At some stations in this region, December 2011 was the warmest such period on record. In Arkhangelsk, the mean monthly air temperature was -1.1°C, 9.2°C above normal (Fig. 7.33). Throughout the month, the daily average temperature was higher than the average maximum temperature (1961–90 base period). On 16 December, a new daily temperature record was established. The last days of December were abnormally warm in northwestern and central European Russia, as well as the Volga Region. Owing to air masses from a warm sector of the deep Atlantic cyclone region, temperature records established in Moscow and St. Petersburg in the 19th century were broken on 27 December. In Moscow, the temperature rose to 5.8°C in the evening of 27 December, which is 2.5°C higher than the previous record established in 1898

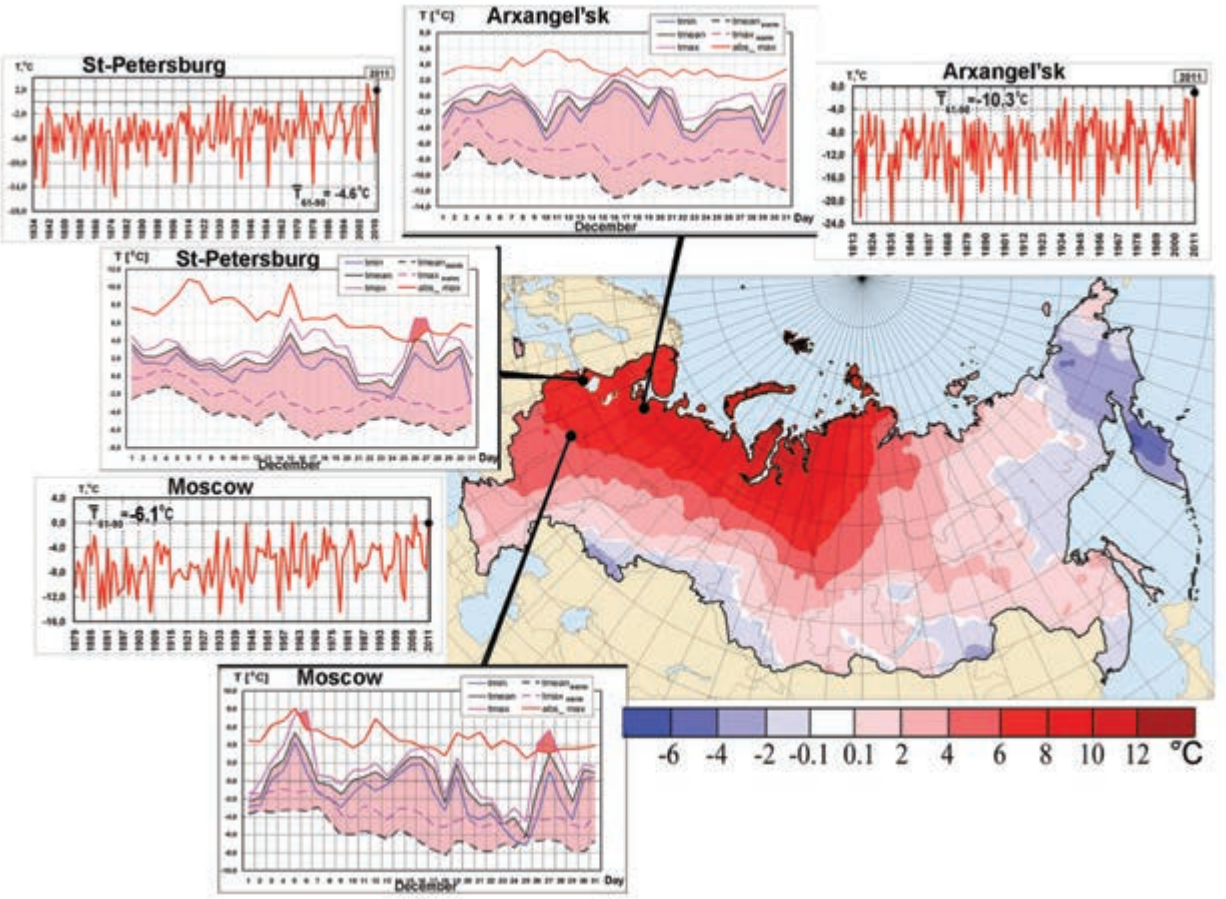

Fig. 7.33. Air temperature anomalies (°C) in December 2011 (1961–90 base period). Insets show the series of mean monthly air temperatures and mean daily air temperatures at meteorological stations Arkhangelsk, St. Petersburg, and Moscow.

(3.3°C). In St. Petersburg, the maximum temperature was even higher, 7.2°C, breaking the previous record of 5.2°C, set in 1881. New temperature records were also established in Kaliningrad, Pskov, Vologda, Tver, Smolensk, Petrozavodsk, Kostroma, Vladimir, Tula, Oryol, Bryansk, Tambov, Kursk, and Lipetsk.

(ii) Precipitation

Precipitation over Russia was generally near normal (80–120%) for the year as a whole. Due to predominantly cyclonic weather over most of European Russia, excessive precipitation was observed in January, from 1.5 to 2 times the monthly normals. The precipitation amount in St. Petersburg was 82.4 mm, or 217% of normal, which is the highest since records began in 1891. Most of Eastern Siberia received below-normal precipitation and the southern Krasnoyarsk Territory, Tyva, and individual areas in Transbaikalia experienced a precipitation deficit. Cold weather with little snow also prevailed in the Maritime Territory. Owing to cyclones over the Sea of Okhotsk, warm weather with snowfalls settled on Sakhalin. In the north of the Sakhalin region, 17 days with snowfalls were recorded in January. In February, a vast low-precipitation zone in European Russia was associated with a region of cold air, lying from northern regions to the Upper Volga (24–80% of monthly normal). By contrast, very heavy precipitation fell in the Amur Region and on the western coast of Kamchatka (300–500% of monthly normal).

In March, northern Siberia and most of the Far East received above-normal precipitation, in places more than three times the monthly normals. Snowfalls during early March in St. Petersburg increased snow supply substantially: on 5 March, the snow depth was 73 cm, the highest amount since records began more than a century ago. The monthly precipitation was above normal in the Upper Volga, mid-Volga, and Ural. In April, heavy precipitation (200–250% of monthly normal) was recorded over a vast region of northern European Russia and northern Western Siberia, with precipitation totals more than twice the

monthly normal in places. A precipitation deficit was recorded in Transbaikalia, at 14–41% of the monthly normal. Heavy rain fell in Northern Caucasia in May. The monthly precipitation normal was exceeded by a factor of two in Chukotka and the Amur Region. In southern Transbaikalia, a precipitation deficit gave rise to extreme fire hazards and forest fires.

In June, a substantial precipitation deficit was recorded in northern European Russia; Altai and Transbaikalia experienced drought conditions that began in the third ten-day period of May. Above-normal precipitation fell in the Urals, Upper Volga, Yakutia, Kamchatka, and Sakhalin. A precipitation deficit was recorded in July in the Southern Urals, northern Kamchatka, southern Khabarovsk Territory, and Amur Region. Western Siberia received copious precipitation that was produced by frequent cyclones. Monthly precipitation was two to three times higher than normal in northern Eastern Siberia. In August, the precipitation-deficit zone covered central and eastern European Russia. Northern Caucasia, particularly Dagestan, received much above-normal precipitation (300–400% of monthly normal).

In the first half of September, northwestern European Russia and the Volga Region experienced heavy rains that ended fire hazards in this region. Most of Western Siberia received below-normal precipitation, with the southern part receiving only 11–30% of normal. Eastern Siberia received below-normal precipitation; only a few individual meteorological stations registered precipitation 20–30% above monthly normal. The precipitation deficit in southern Eastern Siberia contributed to high to extreme fire hazards. On 5–7 September, Typhoon Talas brought very heavy and long-lasting rains to the Maritime Territory and the southern Khabarovsk Territory. The largest amount of precipitation was registered at meteorological stations Sosunovo and Rudnaya Pristan in the Maritime Territory, 266 mm and 249 mm, respectively. In the first half of October, torrential rains occurred in southern European Russia. Settlement Arkhipo-Osipovka, Krasnodar Territory, received 199.1 mm of precipitation in eight hours on 5 October. A significant precipitation deficit was recorded in southwestern Siberia, while most of Yakutia received above-normal precipitation, 160–280%. Prevailing anticyclonic conditions in November contributed to significant precipitation deficits over most of European Russia (20–40% of monthly normal).

In December, a vast low-precipitation zone spread from Transbaikalia to Chukotka. The coast of the Sea of Okhotsk received only 3–10% of its monthly precipitation normal.

(iii) Notable events

- On 9–13 February, 34 avalanches were recorded in Dagestan (Northern Caucasia).
- On 27–28 February, glaze-ice and rime deposition with a maximum diameter of 100 mm was observed in Kabardino-Balkaria (Northern Caucasia).
- On 16 May, the Republic of Buryatia experienced a severe dust storm, with wind speeds of 25–33 m s^{-1}. The storm caused damage to roofs of houses and transmission lines, and toppled trees.
- On 23–27 May, heavy showers caused floods on the rivers in the Krasnodar Territory, with 1312 houses inundated in 16 settlements.
- Floods also occurred in Adygeya (Northern Caucasia). Water rose as much as 6.52 m, which is more than 1 m higher than the dangerous limit; 558 houses were inundated and 12 houses were completely destroyed.
- In June and July, fires were widespread in Transbaikalia (25 fires over an area of 1059 ha and 18 fires over 1142 ha) and the Irkutsk Region (89 forest fires over the area of 20 000 ha).

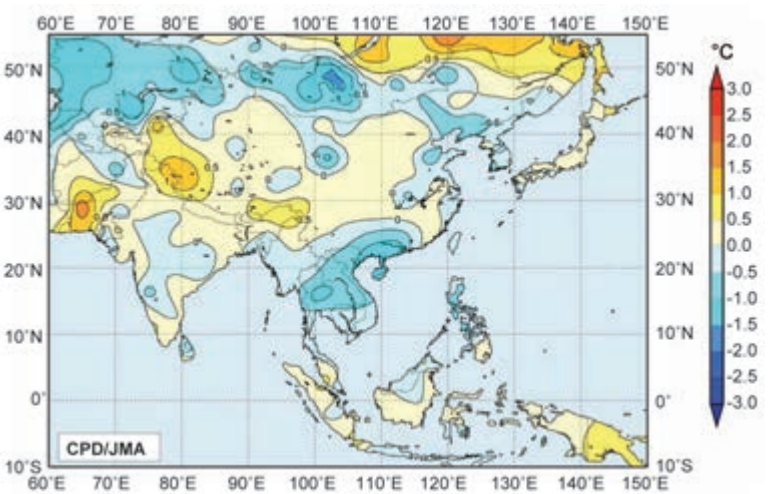

Fig. 7.34. Annual mean temperature anomalies (°C; 1981–2010 base period) over East Asia and surrounding regions in 2011 (Source: Japan Meteorological Agency).

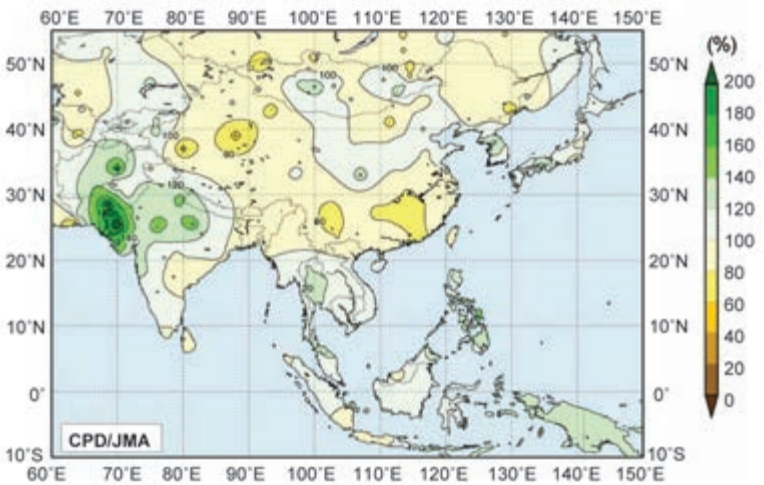

Fig. 7.35. Annual precipitation ratio as percentage of normal (1981–2010 base period) over East Asia and surrounding regions in 2011. (Source: Japan Meteorological Agency)

- On 5 July, heavy rain with hail occurred in Republic of Bashkortostan; 96 mm of precipitation fell in less than three hours.
- In July, drought in the Altai Territory damaged 1883 ha of winter wheat, 250 ha of sunflowers, and 1500 ha of spring crops.
- On 20 July, heavy rain was recorded in the Nizhniy Novgorod Region (European Russia); 91 mm of precipitation fell in less than three hours.
- On 31 July, a rare tornado was recorded in Blagoveshchensk; wind speed at the epicenter was about 40 m s^{-1}. One person was killed and thirteen were injured. The tornado toppled over trees, tore off roofs, turned cars upside-down, and damaged transmission lines.

2) East Asia—P. Zhang, Y. Liu, R. Yamada, J. Shin, and L. Oyunjargal

This region includes China, Japan, Korea, and Mongolia.

(i) Overview

Annual mean temperatures across East Asia showed a nonuniform pattern in 2011 (Fig. 7.34), with positive anomalies over western China and negative anomalies over parts of southern, eastern, and northeast China, the Korean Peninsula, and Mongolia. Annual total precipitation (Fig. 7.35) was near normal in most parts of East Asia. Above-normal precipitation was observed over the Korean Peninsula and parts of Mongolia, while southern and western China received below-normal rainfall.

During January, the East Asian winter monsoon was significantly enhanced due to the pronounced Siberian High and Aleutian Low, leading to extremely low temperatures over wide areas of East Asia. In March, strong cold surges, originating from the Siberian High, occurred over Japan, southern China, and the Indochina Peninsula. In association with the enhanced Asian summer monsoon, the Indochina Peninsula experienced heavy rainfall throughout the monsoon season that caused major floods in Thailand between the 26th and 31st. Forty fatalities were reported and over one million people were affected. In the Surat Thani province, as much as 1270 mm of rain fell during this period (March average rainfall for the province is 51 mm).

(ii) Temperature

The annual mean temperature over China for 2011 was 9.3°C, 0.5°C higher than normal (1971–2000 base period) and 0.2°C lower than 2010, ranking as the 15th consecutive warmer-than-average year since 1997. Except in South China, the annual mean temperatures were above normal over most areas of China, as much as 1°C – 2°C above normal in parts of Xinjiang and Qinghai (in Northwestern China) and Northeast China.

With the exception of winter, average seasonal temperatures were higher than normal in China. The seasonal surface temperature anomalies were -0.3°C, +0.2°C, +0.9°C, and +0.8°C for winter, spring, summer, and autumn, respectively. It was cooler than average in January, with -2.4°C temperature anomalies over the country. However, summer tied with 2007 as the third warmest since 1961. The annual mean hot days (daily maximum temperature ≥ 35°C) across China was 10.6, 3.6 days more than normal, which ranked as the second most since 1961.

The average surface temperature over Japan (averaged over 17 observatories confirmed as being relatively unaffected by urbanization) in 2011 was 0.15°C above the 1981–2010 average. Interseasonal fluctuations in temperature were large, with below-normal temperatures in spring, and above-normal temperatures in summer and autumn. In particular, seasonal mean temperatures for autumn were significantly above normal in eastern and western Japan, and Okinawa/Amami.

The average temperature over South Korea for 2011 was 12.4°C (averaged over 45 weather stations), which was 0.1°C below the 1981–2010 average. The seasonal surface air temperature anomalies over South Korea were -1.2°C, -0.7°C, 0.4°C, and 1.2°C for winter, spring, summer, and autumn, respectively.

The annual mean temperature averaged across Mongolia was -1.0°C, which is 0.6°C lower than the 1979–2008 average. Although monthly average temperature for January was significantly below normal, near-normal temperatures were recorded for all other months.

(iii) Precipitation

In China, the mean annual total precipitation was 556.8 mm, 9% below normal and 18% less than 2010, and ranked the driest since 1951. The total precipitation was below normal consecutively in winter, spring, and summer, but much higher than normal in autumn. The annual rainstorm days were 10.3% less than normal and ranked as the lowest in the past 30 years. Rainstorms occurred mainly in southern northeast China, eastern north China, the middle and lower reaches of Yellow River and Yangtze River Basin, and south China.

The rain belt of the flood season moved northward earlier than normal in 2011, for the beginning of Mei-Yu (the major summer rainfall period along the middle and lower reaches of the Yangtze River basin that usually occurs from 19 June to 9 July; also known as Bai-Yu in Japan and Changma in Korea) and the rainy season of north China was earlier than normal. Although the beginning of Mei-Yu started early with heavier precipitation and stronger intensity than normal, the mean total precipitation of the Yangtze River basin for 2011 was less than 1000 mm for the first year since 1979 and the lowest in the past 33 years. The annual total precipitation of the Huaihe and Zhujiang River basins were below normal and the lowest since 2005. The annual precipitation for the Yellow River basin was higher than normal. North China precipitation was slightly above normal, while Beijing was 125% of normal, marking the first year with annual total precipitation above 700 mm over the past 13 years. In Huaxi (in Western China), autumn rainfall was the highest in the past 36 years.

In Japan, area-averaged annual precipitation amounts were above normal in northern and western regions. At the end of July, record-breaking rainfall was observed in Niigata and Fukushima Prefectures. During autumn, precipitation amounts were above normal nationwide. In particular, record-breaking rainfall occurred in western Japan due to Typhoons Talas and Roke in September.

In South Korea, the mean annual precipitation was 1622.6 mm, 124% of normal, which ranked as fifth highest since 1973 (highest was 142% of normal in 2003). Seasonal precipitation was 108%, 106%, 144%, and 87% of normal for winter, spring, summer, and fall, respectively. South Korea experienced its wettest summer since 1973 because the continuously hot and humid southwesterly flow along the edge of the North Pacific High collided frequently with dry continental air over the Korean Peninsula, resulting in severe atmospheric instability, which caused heavy rainfall.

In Mongolia, above-average precipitation prevailed throughout much of the country. Average precipitation was 191.5 mm, 120% of the 1979–2008 long-term average, making 2011 the third wettest year in the past 40 years. Seasonally, winter was the wettest of all seasons; January and February precipitation was between 1.9 and 2.8 times greater than normal in western, central, and Gobi regions, resulting in an extended period of snow cover in those regions. In May, central and eastern regions experienced 110% of average rainfall and in June, most parts of the country had 230% of normal rainfall. In October and November, snowfall was 1.4 to 3.1 times higher than average in central and south eastern regions and as a result, snow covered 90% of the country.

(iv) Notable events

From late December 2010 to January 2011, the East Asian winter monsoon was significantly enhanced, leading to extremely low temperatures over wide areas of East Asia.

Japan experienced below-normal January temperatures nationwide for the first time since 1986, as well as heavy snowfall on the Sea of Japan side of the country.

In South Korea, a daily minimum temperature of -12.8°C (12.2°C below the 1981–2010 average) was observed on 15 January in Busan, where the weather is usually warmer than other regions of the country in winter. It was the coldest temperature recorded at the station since 1915.

In Mongolia, the monthly mean January temperature was 5.9°C below normal, the second lowest in the last 40 years. In particular, days with minimum temperatures below -45°C continued for two to three weeks in the western region.

In Mongolia, dust and snow storms with wind speeds surpassing 100 km hr^{-1} occurred frequently during spring. On 28–29 April, a strong dust and

snow storm with wind speeds of 58 km hr^{-1} – 144 km hr^{-1} affected much of the country, causing widespread damage.

In South Korea, heavy rainfall occurred in southern and central regions on 9–10 and 26–28 July. During those periods, record high daily and 1-hr maximum precipitations were measured over South Korea. In particular, the total amount of precipitation observed in Seoul during 26–28 July was 587.5 mm, which was the largest amount since record keeping began. On 27 July, the heaviest one-day rainfall since 1907 occurred in Seoul, bringing more than 300 mm of precipitation. The frequency of heavy rainfall events increased in summer. The number of days with heavy rainfall over 30 mm hr^{-1} or 80 mm day^{-1} was 2.8 and 2.9 days, which were 1.3 and 1.1 days above normal, respectively. In particular, the number of days with heavy rainfall above 50 mm day^{-1} was 0.6 in July, the most in South Korea's record extending back to 1973.

In South Korea, the average maximum temperature was 25.9°C in September, 5°C above the 1981–2010 average. The daily maximum temperature reached extreme values in some parts of South Korea. A heat wave warning was issued on 15 September 2011, which was the latest date of the year since heat wave warnings began in South Korea.

In Mongolia, an intense cold front moved through northern region of the country, bringing rain, freezing rain, and snow on mountains on 28 September. During this event, wet snow continued for 11 hours in Darkhan Province and its surroundings, causing $4 million (US dollars) in damage to power transmission lines.

In China, regional meteorological hazards were abrupt and frequent. In early 2011, North China, the Yellow River and Huaihe River basin experienced the most serious autumn–winter drought in the past 41 years. The middle and low reaches of Yangtze River basin experienced the most serious winter–spring drought in the last 60 years, followed by an abrupt transition from drought to flooding in June. Southwestern China experienced the most serious summer–autumn drought in the past 60 years. The Huaxi region (in midwestern China) and Huanghuai regions (in northern China) experienced regional flooding in September. The southern part of South China experienced a serious rainstorm disaster in October. The heavy rainfall caused water logging and inundation in big cities such as Beijing during the summer and autumn. Persistent heat waves hit Jianghuai and Jiangnan in early May, Northwest

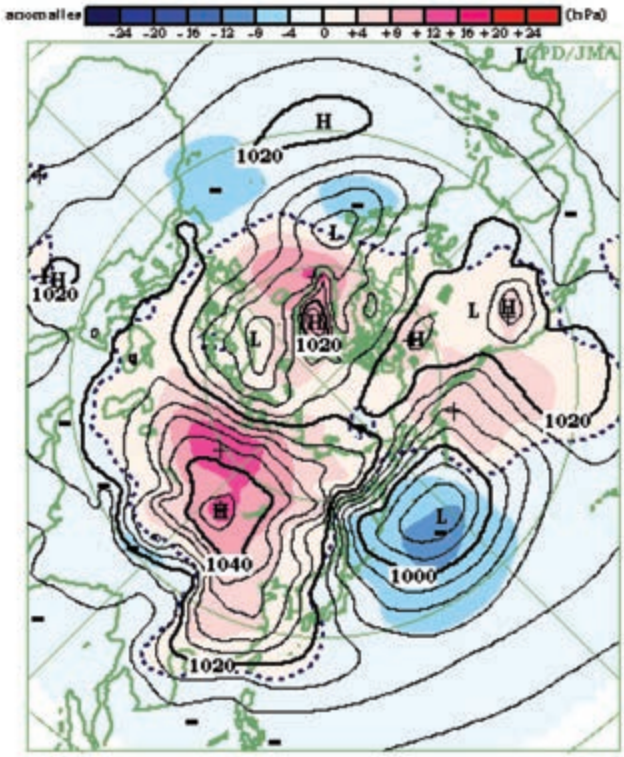

Fig. 7.36. Monthly averaged sea level pressure anomalies (hPa) for January 2011 (1979–2004 base period). The contours show sea level pressure at intervals of 4 hPa. The shading indicates sea level pressure anomalies. JRA/JCDAS data were used in the analysis. (Source: Japan Meteorological Agency)

China and the southern part of North China in June, and most parts of South China in August; maximum temperatures in many areas broke historical records.

In Japan, precipitation totalling 851.1 mm was measured on 19 July over the village of Umaji in Kochi Prefecture due to Typhoon Ma-on, a one-day record for Japan.

Seven tropical cyclones made landfall over China. Direct economic losses of $3.8 billion (US dollars) and associated deaths of 28 people were significantly less than the 1990–2010 average.

Japan was also affected by seven tropical cyclones during 2011, three of which made landfall in July and September. The storms brought heavy rain and strong winds to a wide area of the country, and more than 90 people were killed. See section 4d4 for more detailed information about the western North Pacific tropical cyclone season.

In spring 2011, China was affected by 8 dust and sand events, many fewer than the 1971–2000 normal (19.2) and the 2001–10 average (12.7). The average number of dust days in northern China was 1.7 (3.9 days less than normal), which ranked the third few-

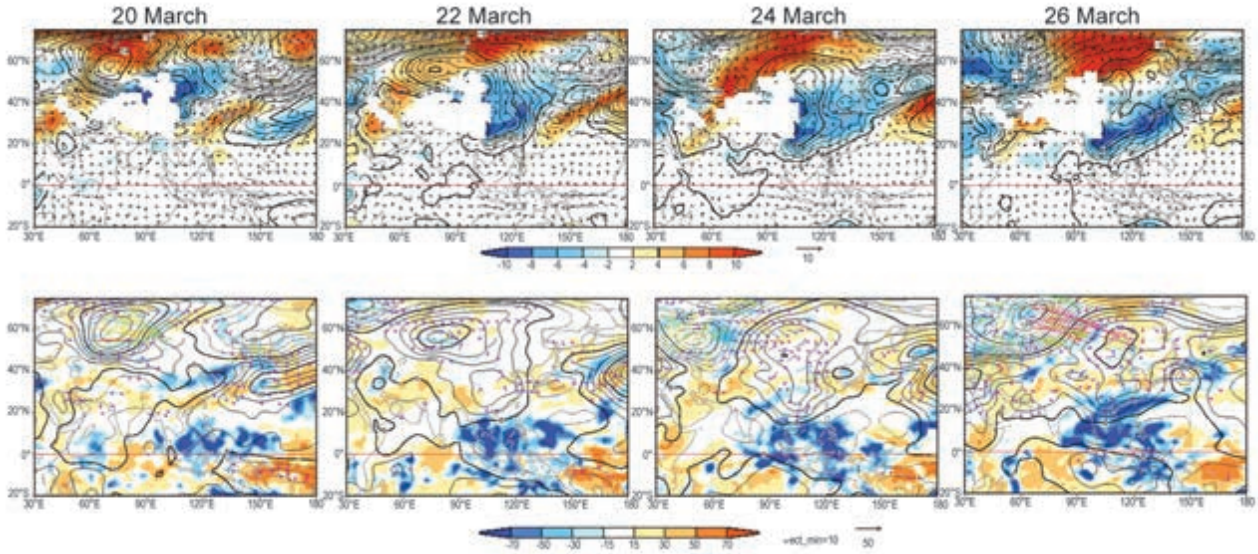

Fig. 7.37. Evolution of cold surges around the South China Sea. The upper panels show anomalies of 10-m wind vectors (m s^{-1}), sea level pressure at intervals of 4 hPa (contours), and 850-hPa temperature at intervals of 2°C (shading); the lower panels indicate 850-hPa wave activity fluxes (m^2 s^{-2}), anomalies of 850-hPa stream function at intervals of 2.5 × 10^6 m^2 s^{-1}, and OLR (W m^{-2}) (1979–2004 base period). JRA/JCDAS data were used in the analysis. (Source: Japan Meteorological Agency)

est since 1961. And the date of the first event was 12 March, which was the latest since 2001. On 28–30 April, a dust storm affected 11 provinces of China, the most affected by a single storm in 2011.

In Japan, Kosa (yellow sand/aeolian dust) was observed over a large area at the beginning of May. A cumulative total of 194 observations of Kosa were made in May, which was about six times higher than average (32.9) and marked the highest figure for the month since records began in 1967. While there were 14 days in which any meteorological station in Japan observed Kosa in 2011, which was below the normal number of 24.2 days, a cumulative total of 220 observations of Kosa were made in the year, which was near normal (225.3).

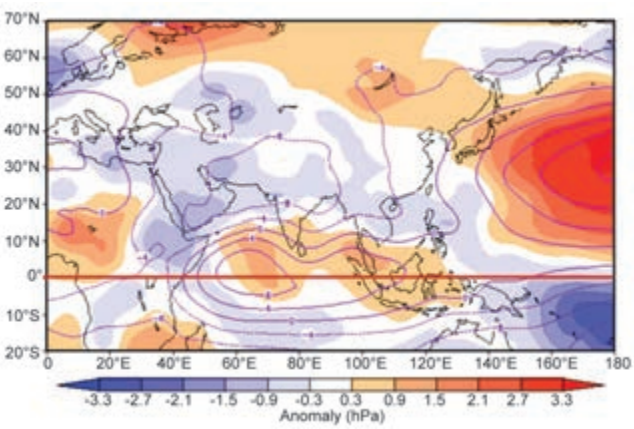

Fig. 7.38. Four-month mean 850-hPa stream function and its anomaly for Jun–Sep 2011. The contours indicate the 850-hPa stream function at intervals of 4 × 10^6 m^2 s^{-1}, and the color shading indicates 850-hPa stream function anomalies from the normal. In the Northern (Southern) Hemisphere, warm (cold) shading denotes anticyclonic (cyclonic) circulation anomalies (1981–2010 base period). JRA/JCDAS data were used in the analysis. (Source: Japan Meteorological Agency)

(v) Monsoon

During late December 2010 and January 2011, the East Asian winter monsoon was significantly enhanced, leading to extremely low temperatures over wide areas of East Asia. In the upper troposphere, ridges were seen over the western part of Siberia, and blocking highs developed over the eastern part in January. These conditions were suitable for the enhancement of the Siberian High. The Aleutian Low was enhanced to the east of Japan in January (Fig. 7.36), although it was obscure in December and February. The pronounced Siberian High and Aleutian Low led to a strong winter monsoon over East Asia in January.

The Siberian High was significantly developed in March. High surface pressure southwest of Lake Baikal peaked around 20 March with an extremely cold air mass in the lower troposphere (Fig. 7.37). Thereafter, high-pressure anomalies related to this cold air mass propagated southward along the eastern periphery of the Tibetan Plateau and reached the South China Sea and the Indochina Peninsula late in the month, bringing significant cold surges.

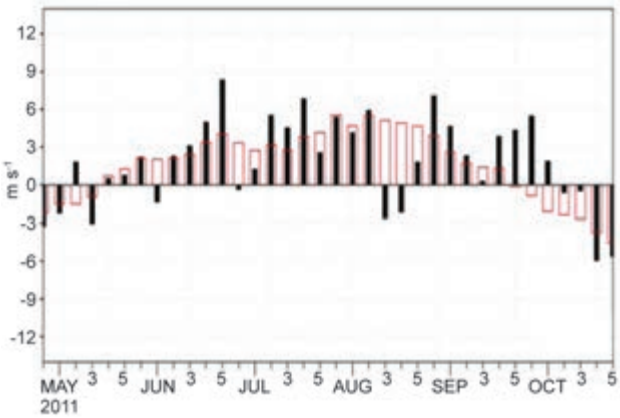

Fig. 7.39. Variation of pentad zonal wind index (m s^{-1}) over the monitoring region (10°N–20°N, 110°E–120°E). Red open bars represent the climatology. (Source: China Meteorological Administration)

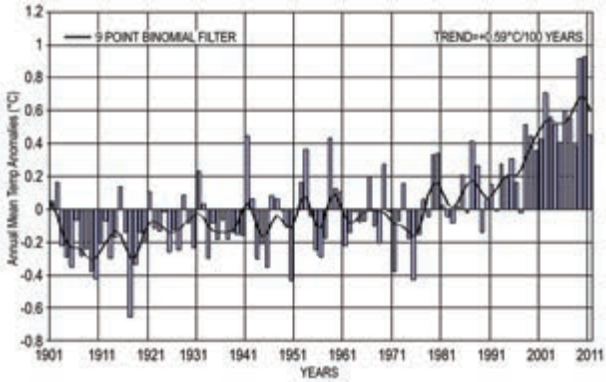

Fig. 7.41. Annual mean temperature anomalies (°C, 1961–90 base period) averaged over India for the period 1901–2011. The smoothed time series (9-point binomial filter) is shown as a continuous line.

In conjunction with these surges, convective activity was enhanced over the South China Sea and the Indochina Peninsula as well as over the Maritime Continent, where it was strengthened due to La Niña. The intensity of northerly surges around the South China Sea was the strongest for March since 1979.

Convective activity (inferred from outgoing longwave radiation, OLR) for June–September 2011 was enhanced over southern Pakistan, the eastern Arabian Sea, the Bay of Bengal, the Indochina Peninsula, the Philippines and the western Pacific, while it was suppressed over the eastern Indian Ocean and Indonesia. In the upper troposphere, the Tibetan High was pronounced over a broad area. In the lower troposphere, a prominent monsoon trough was observed stretching from northern India to the Philippines, and westerly/southwesterly winds were stronger than normal over a large area from the Arabian Sea to the Philippines (Fig. 7.38). These characteristics of convective activity and atmospheric circulation indicate that the Asian summer monsoon was active.

From May to August, equatorial intraseasonal oscillations were observed propagating eastward with a period of less than 30 days. The areas of active convection originally enhanced by these oscillations were seen to propagate northward around India and east of the Philippines. In October, the active phase of a large-amplitude Madden-Julian oscillation (MJO) propagated eastward from northern South America to the Indian Ocean, and convective activity over the western Pacific, which tends to be enhanced until September, was suppressed.

The South China Sea summer monsoon (SCSSM) in 2011 broke out in the second pentad of May, two pentads earlier than normal, and withdrew in the third pentad of October, three pentads later than normal (sixth pentad of September). The intensity of the SCSSM was -1.34, which was weaker than normal (Fig. 7.39). From the onset monsoon to the first pentad of June, the front of the East Asian subtropical summer monsoon (EASSM) maintained over the region from South China to the south of the Yangtze River valley. In the second pentad of June, the front of the EASSM advanced to the Yangtze River valley, and the Mei-yu period started. With the northward moving of the West Pacific Subtropical High (WPSH), the major rain belt correspondingly moved northward. In the sixth pentad of June, the rain belt in eastern China northward advanced to North China and then North China entered rainy season. In the fifth pentad of July, with the ridge of the WPSH retreating southward, the rain belt in

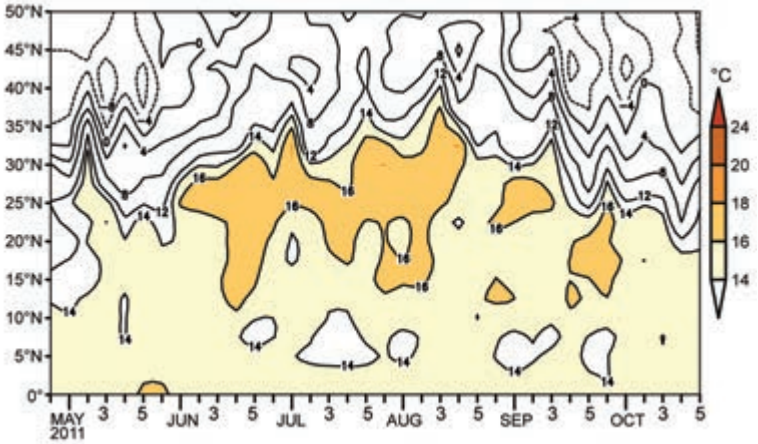

Fig. 7.40. Latitude–time section (110°E–120°E) of pseudo-equivalent potential temperature (°C). (Source: China Meteorological Administration)

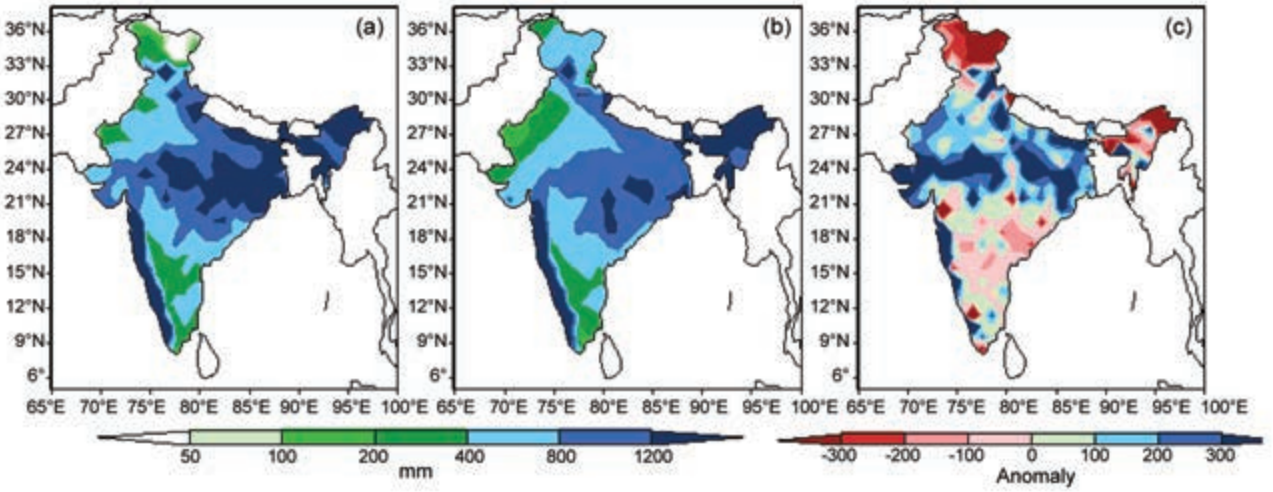

Fig. 7.42. Spatial distribution of monsoon seasonal (Jun–Sep) rainfall (mm) over India in 2011: (a) actual, (b) normal, and (c) anomalies.

eastern China shifted from southward North China. From the second pentad of September, the autumn rain in West China started. Due to tropical cyclone activity during the fifth pentad of September, warm and wet air was maintained over the South China Sea and the tropical western Pacific, which resulted in persistent heavy precipitation over South China. In the third pentad of October, with cold air from the north intruding into the coastal areas and the South China Sea, the thermodynamic property of the air mass changed. The front of the summer monsoon then began to withdraw from the South China Sea and weaken (Fig. 7.40).

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

This region includes India, Pakistan, and Sri Lanka.

(i) Temperatures

South Asia experienced warm temperatures in 2011. While India had relatively few heat wave events, Pakistan experienced several heat waves during the summer months. Severe heat wave events were reported in different parts of Pakistan in the last week April, the second week of May, and the first week of June. During these events, maximum temperatures were above normal by 6°C to 7°C. Pasni (Balochistan) recorded 50°C on 20 May, while the port city of Karachi reported 46°C on 21 May, which was the hottest day at Karachi in the past 30 years.

The annual mean temperature anomaly for India in 2011 was +0.45°C above the 1961–90 average, making it the ninth warmest year on record since national records began in 1901 (Fig. 7.41; 2009 was the warmest at +0.93°C). Abnormally warm temperatures (+0.85°C above average) during the post-monsoon season (October–December) contributed heavily to the positive annual temperature anomaly.

(ii) Precipitation

The summer monsoon season (June–September) contributes 60–90% of the annual rainfall over major portions of South Asia. In 2011, the region experienced normal monsoon rainfall activity. However, while India received normal rainfall, Pakistan experienced one of its worst floods during the summer monsoon season.

For India, the long-term average of the summer monsoon rainfall (1941–90 base period) is 890 mm. For 2011, the summer monsoon seasonal rainfall averaged over the country as a whole was 102% of normal. While the northern plains experienced above-normal rainfall activity, deficient rainfall was reported from northeastern parts and south peninsula (Fig. 7.42). In 2011, the monsoon onset over southern parts of India occurred on 29 May, which

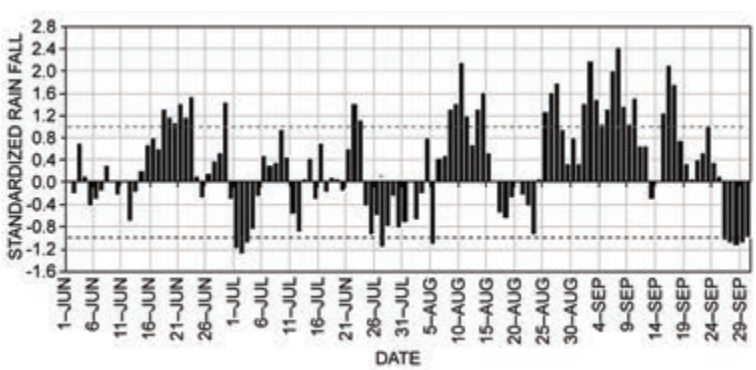

Fig. 7.43. Daily standardized rainfall time series averaged over the monsoon core zone over India (1 Jun–30 Sep 2011).

Table 7.1. Record 24-hr rainfall over India during the 2011 monsoon season.					
Station	**24-hr Rainfall (mm)**	**Date**	**Previous Record (mm)**	**Date of Record**	**Year of Record**
Kotaap	122.1	29 Jun	108.9	29 Jun	1977
Guna	337.2	23 Jun	191.5	29 Jun	1945
Damoh	275.8	22 Jun	103.6	8 Jun	1971
Sagar	165.0	23 Jun	158	28 Jun	1945
Vijaywada AP	115.9	7 Jun	64	12 Jun	1983
Phoolbagh	149.8	1 Jul	123.6	11 Jul	2003
Buldhana	166.0	8 Jul	122.9	25 Jul	1953
Guwahati AP	169.4	5 Aug	135.7	19 Aug	2005
Mukteswar	234.3	16 Aug	203.7	24 Aug	1948
Tehri	132	16 Aug	110.1	13 Aug	1970
Phoolbagh	209.4	16 Aug	193.2	19 Aug	2003
Nimach	258.8	9 Aug	185.9	15 Aug	1957
Chennai City	156.2	25 Aug	100.3	20 Aug	2008
Gadag	93	20 Aug	89.6	2 Aug	2002
Kenjorgarh	193.2	23 Sep	178.4	12 Sep	1963
Jaisalmer	88.2	2 Sep	81.2	9 Sep	2005
Dwarka	303.6	6 Sep	135.9	4 Sep	1921
Bhuj AP	194.9	7 Sep	176.1	15 Sep	1984
Okha	147.4	6 Sep	88	18 Sep	2005
Rajnandgaon	107.6	7 Sep	103	5 Sep	1994

was three days earlier than normal. The monsoon steadily advanced until 26 June, covering most parts of the country, except the northwest. After a hiatus of about two weeks, the monsoon covered the whole country on 9 July, about six days earlier than normal. During the season, rainfall over the country was well distributed in time, except in July. Rainfall for the country as a whole in June was 112% of normal. Rainfall in July was 85% of normal. However, rainfall activity was above normal both in August (109% of normal) and September (108% of normal).

During the monsoon season, 7 of 36 meteorological subdivisions received excess rainfall, 26 received normal rainfall, and 3 received deficient rainfall. Of 603 meteorological districts for which data are available, 76% received excess/normal rainfall and the remaining 24% received deficient/scanty rainfall during the season. On the daily time scale, the rainfall distribution over the country was generally above or near normal on most of the days of the season, except for some days in July and September (Fig.7.43). Over the North Indian Ocean, ten low pressure areas were formed during the season, of which four systems intensified into monsoon depressions (one over land). However, two of the monsoon depressions were short-lived. Table 7.1 lists record 24-hr rainfalls that occurred during the 2011 monsoon season.

During the winter (January–February) season, rainfall over the country was 80% of normal, while during the premonsoon season (March–May), rainfall was 89% of normal.

Pakistan, at the western edge of the pluvial region of the South Asian monsoon, receives more than half of its annual rainfall during the summer monsoon season (July–September). The summer monsoon typically sets over northeastern parts of the country around 1 July, with a standard deviation of five days. The 2011 summer monsoon was set on 28 June. The most significant feature of this monsoon season was the record-breaking heavy rainfall over parts of Sindh province. The 2011 monsoon seasonal rainfall averaged over Pakistan was 172% of normal (1961–90 base period) and ranked as the fifth heaviest monsoon rainfall over the past 52 years. Even though rainfall activity in July was only 83% of normal, the remaining two months experienced above-normal rainfall activity. Sindh province experienced exceptionally heavy rainfall (347% of normal) during the season, which was the second heaviest seasonal rainfall since 1961. Most of the rain fell in a four-week period from mid-August to early September. Some stations, including Mithi (1348 mm), Mirpur Khas (866 mm), Nawabshah (650 mm), Chhor (552 mm), and Dadu (485 mm), recorded very heavy rainfall that exceeded historical seasonal records. Mithi (Sindh) received 300 mm of rainfall during 1–14 September in four consecutive spells of monsoon rains, which is an all-time record. The heavy rainfall over the Sindh province was attributed to mid-tropospheric cyclones (MTC) that formed over the northeastern Arabian Sea and adjoining northwestern parts of India during late August and early September. The devastating floods affected millions of people, damaged millions of houses, damaged agricultural crops, and claimed at least 250 lives. The 2011 flooding were the worst since the 2010 floods, which devastated the whole country.

Overall, Sri Lanka's total annual rainfall for 2011 was near normal; however, there were large seasonal and regional variations, with sustained regional deficits during March, February, June, July, August, and September. Five episodes of intense rainfall peaking on 6 January, 29 January–4 February, 28 October, 24 November, and 25–30 December compensated for the periods of deficit. The heavy rainfall over the eastern coastal region peaking on 6 January and the impacts of a tropical depression that led to heavy rainfall around 24 November over the southern coast led to loss of life and damage to fisheries and other coastal infrastructure. During 2011, La Niña conditions prevailed from January to April and from September to December. Usually during La Niña episodes, rainfall in Sri Lanka is augmented modestly from January to April, there is a slight increase during June to September, and there is a decline from October to December. During 2011, there were significant departures from this pattern, in part due to an unusual pattern of La Niña influences over the Indian Ocean region and due to heavy rainfall events related to storms and other weather events during January, February, October, November, and December.

The northeast monsoon (NEM) normally sets in over southern peninsular India during October and over Sri Lanka in late November. The NEM contributes 30–50% of the annual rainfall over southern peninsular India and Sri Lanka as a whole. The 2011 NEM seasonal rainfall over south peninsular India was 96% of normal. The rainfall over Sri Lanka and northern Maldives during this season was slightly enhanced.

(iii) Notable events

Severe cold wave conditions prevailed over northern parts of India during the first two weeks of January and also during the second half of December 2011. Maximum temperatures at a number of stations over the northern plains were 5°C – 10°C below normal on many days during January. The cold wave claimed about 500 lives (approximately 250 alone in the state of Bihar) during January and about 150 lives during December. The cold air that impacted parts of India during the first week of January moved into Bangladesh during the second and third weeks of the month. Night temperatures in Bangladesh were 5°C – 10°C below normal during the month, which had an adverse impact on agriculture.

In January, heavy snowfall up to 3 m across the high mountain passes of Rohtang and Kunzam cut off access to portions of far northern India including the Kashmir province.

Dust storms/thunderstorms/lightning accompanied by heavy rains during the premonsoon season claimed over 100 lives in the northern parts of India.

Mumbai city was unusually warm during 12–17 March. Colaba Observatory in Mumbai reported 41.6°C on 16 March, which was 10.5°C above normal and was the all-time highest temperature recorded at that location. Similarly, two other observatories in coastal districts, Ratnagiri (south of Mumbai) and Dahanu (north of Mumbai), also reported record high maximum temperatures, 40.9°C (10.1°C above normal) and 40.6°C (9.4°C above normal), respectively, on the same day.

Table 7.2. Seasonal amount of precipitation and temperature over Iran in 2011.

Parameter	Season		Winter	Spring	Summer	Autumn
Precipitation	Average (mm)		118	42	14.5	71
	Respect to (%)	Long term	8%	27%	44%	14%
		previous year	37%	32%	200%	300%
	Range from–to (mm)		4 to 697	0 to 353	0 to 772	0 to 1293
Temperature	Respect to long term		-2.1 to 2.2	-1.0 to 2.6	-1.5 to 2.5	-9.9 to 4.5
	Range from-to (°C)		-6.2 to 22.1	8 to 35	16 to 39	1.7 to 27.2

*red: above long term, blue: below long term, dashed: mixed below and above long term

The death toll due to heavy rains and floods in different parts of India during the southwest monsoon was more than 300, mostly in the northern and central parts of the country. Heavy rainfall over the south peninsula in November 2011, due to northeast monsoon activity, killed more than 90 people in the state of Tamil Nadu. Very Severe Cyclone Thane (as designated by the India Meteorological Department) formed over the southeast Bay of Bengal on 26 December and crossed the north Tamil Nadu coast (southeast India) on 30 December, claiming at least 50 lives and causing widespread damage.

4) Southwest Asia

This regional includes Iran and Turkey. Information from Iraq is unavailable this year.

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

Surface air temperatures were mostly cool across Iran during winter and autumn 2011, while the spring and summer experienced above-normal temperatures over most parts of the country. Mixed patterns including seasons with much-below- and above-normal temperatures have been common in recent decades, accompanied by a long-term increase in temperature. Annual minimum and maximum temperatures in Iran have increased by 0.4°C – 0.5°C and 0.2°C – 0.3°C decade^{-1}, respectively, over the 1960–2010 period (ASMERC 2011).

In 2011, Iran experienced wetter-than-normal conditions for winter, summer, and autumn (Table 7.2). These seasons also received more precipitation than they received in 2010. However, the statistics show a decreasing trend of precipitation over the longer term (1960–2010) (ASMERC 2011). Table 7.3 shows the amount of precipitation during August and November, and for summer and autumn, for several stations where precipitation amounts were higher than normal.

Generally, observed data for 2011 and recent results on longer-term variability (ASMERC 2011) show

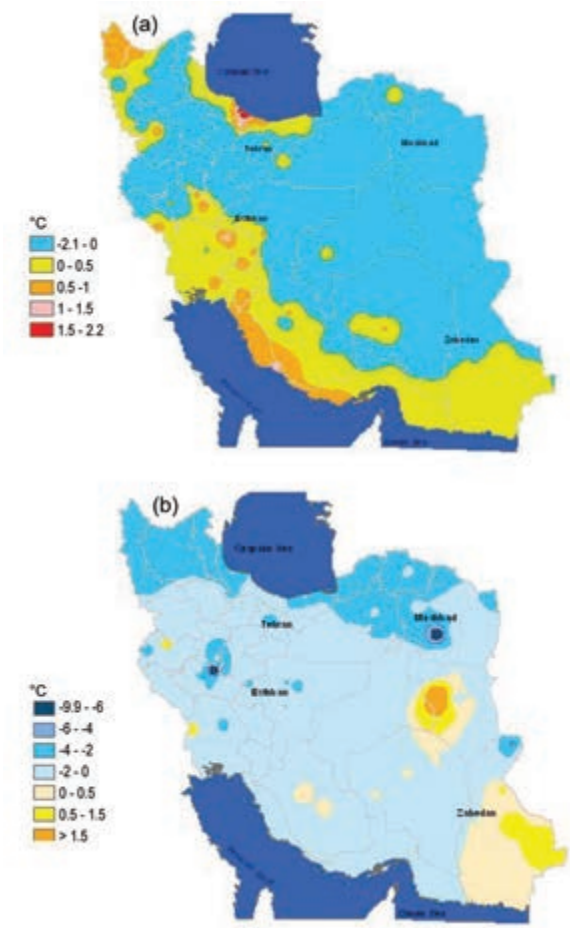

Fig. 7.44. Seasonal mean surface temperature anomalies (°C) in Iran in (a) winter and (b) summer 2011. (Source: I.R. of Iran Meteorological Organization)

Table 7.3a: The amount of precipitation (mm) in August 2011 and average of precipitation in long term for August and summer for a number of stations in Iran.

Stations	August 2011	Long-term average (Aug)	Summer 2011	Long-term average (Summer)	Ratio of summer 2011 precip against long term average
Baft	43.7	3	47.1	13.3	>3
Zabol	22	0.01	22	0.08	>200
Kerman	13.8	0.3	13.8	0.8	>17
Ghazvin	42.7	1	55.6	5.3	>10
Karaj	46.9	0.6	48.9	5.7	>8
Chitgar	42.5	0.5	42.9	5.7	>7
Tehrann-Mehrabad	22.3	1.1	23.11	5.4	>4
Abali	74.1	6.8	103	29	3.5

Table 7.3b: As in (a) but for November and autumn 2011.

Stations	November 2011	Long-term average (Nov)	Autumn 2011	Long-term average (Autumn)	Ratio of summer 2011 precip against long term average
Esfehan	77.2	9.0	93.5	26.7	>3
Naien	31.8	7.0	59.0	19.0	>3
Tehran	179.0	22.5	186.0	70.0	>2.5
Golpaigan	196.9	25	202	75	>2.5
Geophysic	232.8	40.5	239.5	107	>2
Moaelmkleiyep	158	35.5	170.4	88.0	>1.5
Bijar	107	44.5	121	89.0	>1.5
Lordgan	168.5	43.5	201.8	155	>1.3

an increase in interannual and longer term variability of temperature and precipitation over time.

(A) Temperature

During winter 2010/11 (Table 7.2), the country experienced temperatures mostly 0° to 2°C below average. However, some parts of the coastal area both in the north and south (including the area across the Caspian Sea, the Persian Gulf, and the Oman Sea), and individual small areas in the southwest and southeast recorded anomalies of +2°C (Fig. 7.44a).

Warmer-than-average conditions occurred across most of the country, except in a limited area in the west in spring. The highest values occurred in parts of the east, including Khorasan Rasavi and Semnan Provinces, part of Yazd Province, and Bandarabbas station, with anomalies more than +2°C. During summer, average temperatures were 0.5°C – 1.5°C below average in limited areas distributed over the country, while the rest of the country experienced temperatures 1°C – 2°C above the long-term average, with anomalies of up to +3.8°C observed at Zabol station in the southeast (Fig. 7.44b). During autumn, a severe cold spell persisted across the country, accompanied by heavy precipitation and high winds, while warmer-than-average conditions of +1°C were limited to a small part in the southeast. Average temperatures were about 2°C – 4°C below the long-term averge. Broujerd, Kashmar, and Khakhal stations in the northwest recorded -12°C, -8.9°C, and -8.3°C anomalies, while Saravan, Zahedan, and Iranshahr stations in the southeast recorded anomalies of +1.1°C, +1.1°C, and +0.6°C, respectively.

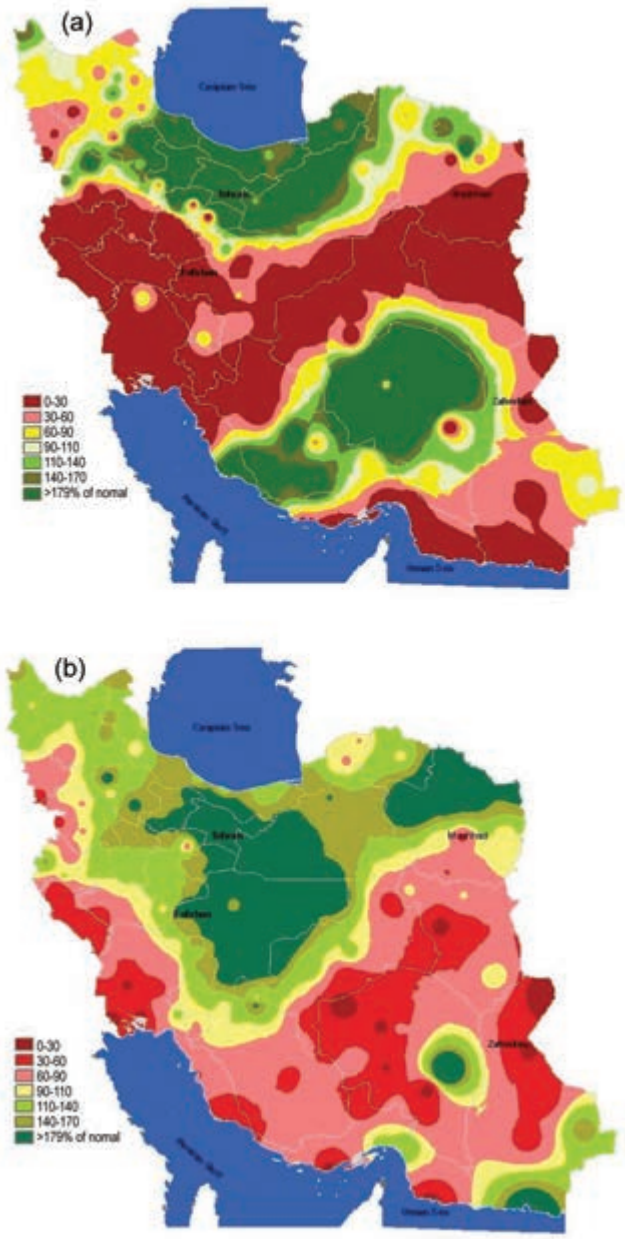

Fig. 7.45. Seasonal precipitation anomalies (%) in Iran in (a) spring and (b) autumn 2011. (Source: I.R. of Iran Meteorological Organization)

(B) Precipitation

During winter 2010/11 (Table 7.2), areas with average or above-average rainfall (up to 170% of normal) were confined to the southeast, areas around the Caspian Sea, parts of the northwest, and small parts in the south of the Zagross mountains. A small part of Yazd province received less than 60% of normal rainfall, while the rest of the country received precipitation amounts between 60% and 90% of normal. Similar to 2010, the largest 2011 total rainfall of 697 mm fell in Bandar Anzali, located in the southwest of the Caspian Sea area, followed by 682 mm in the southern Zagross mountain area. Through the middle and east of the country, and in localized regions in Sistan and Balochestan Province (across the Oman Sea), winter rainfall was less than 25 mm.

In spring, the amount of precipitation was 30–90% of normal across most of the country, but up to 170% of normal in the west and northwest. In contrast to the previous year, the spring of 2011 was the only season of the year where total precipitation was below normal. During spring (Fig. 7.45a), one-third of the country (middle band of Iran) received no measured rainfall, and less than two-thirds received less than 50 mm precipitation. Only the north, including the area across the Caspian Sea, the Alborz mountain area, and some small limited areas scattered across the country experienced more than 50 mm precipitation. These areas, in addition to some eastern coastal areas, received above-normal precipitation, while the rest of the country received below-normal precipitation (similar to 2010). The highest recorded precipitation was in Bandar Anzali with 772 mm.

During autumn, the entire country, except the east and southeast, received precipitation between 25 mm and 250 mm and even up to 1200 mm in the Caspian area. Precipitation was less than normal over the southern half of the country, but over 170% of normal in the north and northeast of the country, as in spring (Fig. 7.45b).

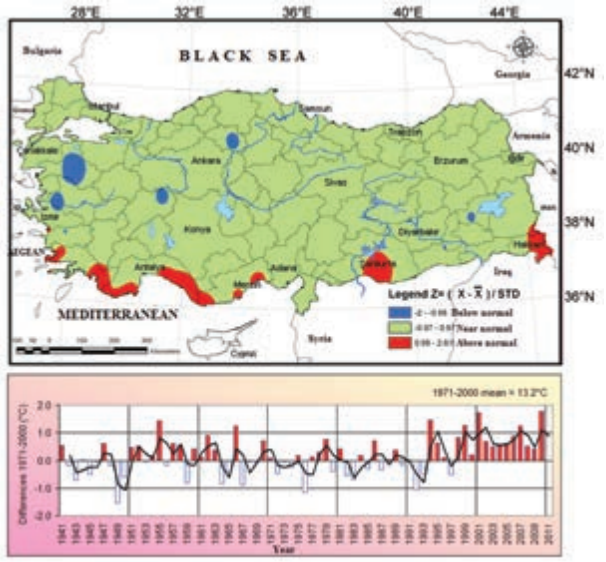

Fig. 7.46. (top) Spatial mean temperature anomalies (°C) in Turkey in 2011 (colors indicate terciles); (bottom) time series of annual mean temperature anomalies in Turkey.

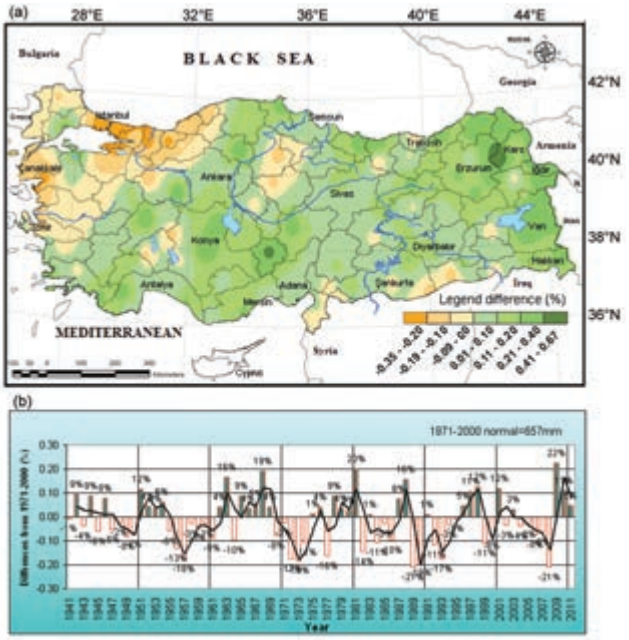

Fig. 7.47. (a) Spatial mean precipitation anomalies in Turkey in 2011 (standard deviations); (b) time series of annual precipitation anomalies in Turkey (%).

(ii) Turkey—S. Sensoy, Y. Ulupınar, S. Kervankıran, and M. Demircan

(A) Temperature

Although there were significant temperature anomalies in individual months, Turkey's annual mean temperature in 2011 was near normal (1971–2000 base period) of 13.2°C, based on records from 130 stations (Fig. 7.46). Much of the country had near-normal temperatures overall, although a number of areas in the south had above-normal temperatures while a few regions (Manisa, Balıkesir, Emirdağ, Çankırı Batman, and Bitlis) recorded below-normal annual mean temperatures (Fig. 7.46). Monthly mean temperatures were above normal in January, February, March, July, August, and September while April, May, October, and November were below normal. June and December temperatures were near normal.

(B) Precipitation

The rainfall distribution in Turkey is strongly affected by topography. On average, coastal stations and inland stations exhibit large differences in rainfall. Averaged over the country, Turkey received 687 mm total precipitation for 2011, 30 mm above normal (1971–2000 base period). Precipitation was also above normal in 2009 and 2010. During 2011, large parts of the country received above- or near-normal precipitation while Marmara, the northwest Aegean and western Black Sea regions, and Antakya, Isparta, Eskişehir, Yozgat, Ceylanpınar, İslahiye, Mardin and Bitlis received below-normal rainfall (Fig. 7.47). Precipitation in Sarıkamış and Niğde's were 167% and 149% of normal, respectively. Monthly precipitation was above normal during February, April, May, June, September, and October and below normal during January, March, July, August, November, and December.

(C) Notable events

A total of 324 extreme events were reported in Turkey during 2011, fewer than in 2009 or 2010 (Fig. 7.48). Nearly 36% (112) of these events were hail, while floods accounted for 28% of extremes and storms 20%.

Due to flooding in Gaziantep on 11 April, cars and ground floors in many buildings became unusable.

During a hail storm in Ankara on 16 June, up to 20 cm of hail stones accumulated on the ground. Some underpasses were closed because the hail blocked the exits, and traffic was significantly disrupted.

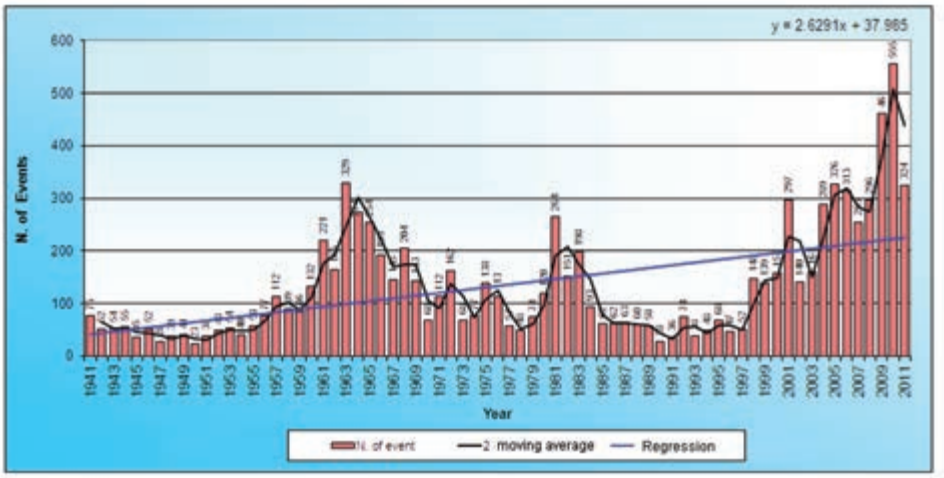

Fig. 7.48. Annual count of extreme events in Turkey.

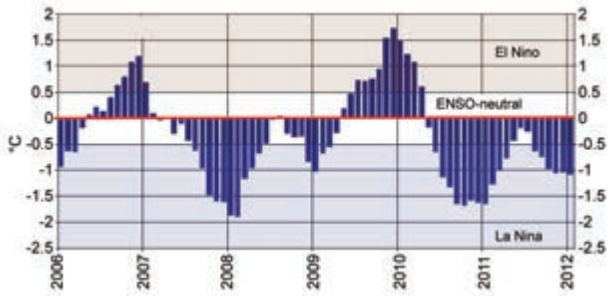

Fig. 7.49. Time series of the Niño 3.4 SST anomaly (°C) for the period Jan 2006–Jan 2012. La Niña has dominated the climate of the Pacific basin for much of this time period, with 33 months (45%) having SST in the La Niña category (light blue shaded region). Over the past 30 years, the state of the climate has been in La Niña, El Niño, and ENSO-neutral 29%, 26%, and 44% of all months respectively. Moderate-to-strong La Niña occurred in late 2007 to early 2008, and again in the latter half of 2010 through early 2011. A brief period of ENSO-neutral in the boreal summer of 2011 was followed once again by a return to a weak-to-moderate La Niña by the fall of 2011.

(h) Oceania

[Southwest Pacific section not available in 2011]

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

(i) Overview

This assessment covers the area from the international date line west to 130°E, between the equator and 20°N. It includes the US-affiliated islands of Micronesia, but excludes specific discussions concerning the western islands of Kiribati and nearby northeastern islands of Indonesia. In this Pacific region, the climate is strongly influenced by the phase and phase changes of ENSO (section 4b).

The state of the climate of the Pacific basin in 2011 began as a moderate-to-strong La Niña (Fig. 7.49). ENSO-neutral conditions were present by May. ENSO-neutral conditions prevailed through the boreal summer (JJA), and by October 2011, La Niña conditions returned (weak to moderate by the end of the year). Temperature, rainfall, sea level, and tropical cyclone (TC) distribution all roughly corresponded to the behavior that would be expected in a year that experienced the described ENSO conditions. Such years tend to be rather wet, with fairly normal temperatures, but minimal TC activity. Sea levels are generally elevated.

During the first half of 2011, Micronesia experienced relatively strong easterly trade winds and a well-developed near-equatorial convergence zone or intertropical convergence zone (ITCZ) that brought above-normal rainfall to most locations. The midyear transition to ENSO-neutral conditions allowed monsoon activity to render the western half of Micronesia very wet during the boreal summer, while the August–October transition back into La Niña maintained the generally wet pattern, but shifted TC activity west of Micronesia. During the brief period of ENSO-neutral conditions, the western Pacific monsoon reached eastward as far as Guam and the Commonwealth of the Northern Mariana Islands (CNMI), with several episodes of weak to moderate southwesterly surface winds observed during July–September. However, with the return of La Niña later in the year, the monsoon made an early retreat from Guam and the rest of Micronesia. From October through the end of the year, widespread anomalous easterly surface winds returned, TC activity in Micronesia was greatly reduced, and abundant rainfall eased to monthly values at or below normal throughout the region.

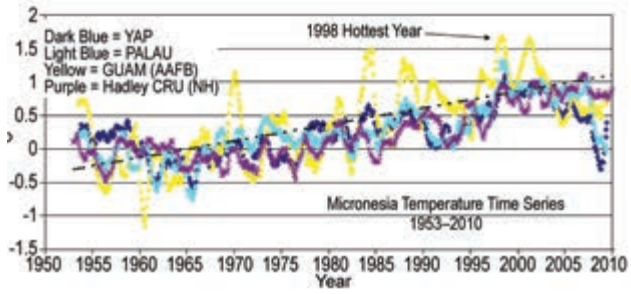

Fig. 7.50. Time series of MaxT anomaly (°C) at AAFB, Koror, Yap, and the Northern Hemisphere. Values are a 12-month moving average of the monthly averages.

(ii) Temperature

Average monthly maximum temperatures (maxT) and minimum temperatures (minT) across most of

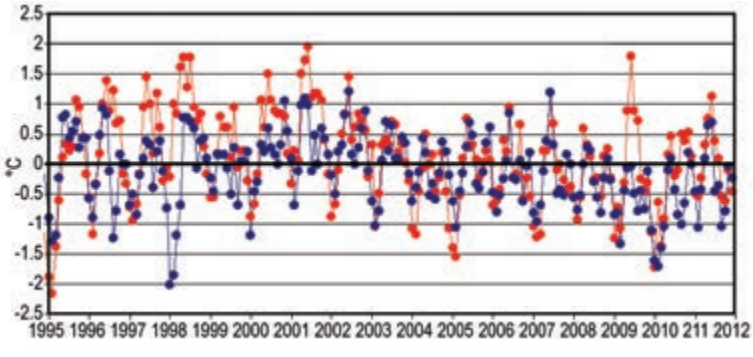

Fig. 7.51. Time series of anomalies (°C) of MaxT (red) and MinT (blue) at AAFB. Anomalies are with respect to the 1981–2010 mean values; thus, the annual cycle is present.

Table 7.4. Maximum and minimum temperature anomalies and rainfall anomalies for selected Micronesian locations for Jan–Jun 2011 and for Jul–Dec 2011. Maximum and minimum temperature anomalies are in °C month^{-1} and rainfall anomalies are in mm. "N" is the normal rainfall taken from the 1981–2010 base period. Locations (latitude and longitude) are approximate. NA indicates that the temperature normals are not available. Kapinga stands for Kapingamarangi Atoll in Pohnpei State, Federated States of Micronesia (FSM).

Location	Max Temp Min Temp		Rainfall							
	Jan–Jun	Jul–Dec	Jan–Jun	Jan–Jun	Jan–Jun	Jul–Dec	Jul–Dec	Jul–Dec	Jul–Dec	Jan–Dec
	°C mo^{-1}	°C mo^{-1}	N mm	2011 mm	%	N mm	2011 mm	%	2011 mm	%
Saipan 15°N,146°E	+0.34 +0.30	-0.14 +0.07	449.1	969.0	215.8	1322.8	1240.8	93.8	2209.8	124.7
Guam 13°N,145°E	+0.66 +0.72	+0.03 -0.06	691.6	932.9	134.6	1788.4	2000.0	111.8	2933.0	118.3
Yap 9°N,138°E	+0.37 -0.06	+0.44 -0.12	1169.7	1642.6	140.4	1902.0	2363.0	124.2	4005.6	130.4
Palau 7°N,134°E	+0.29 -0.04	+0.15 -0.26	1717.6	2617.2	152.4	2032.5	2612.1	128.5	5229.4	139.4
Chuuk 7°N,152°E	+0.80 +0.24	+0.35 +0.15	1584.2	1957.3	123.6	1833.1	2204.5	120.3	4161.8	121.8
Pohnpei 7°N,158°E	+0.15 -0.17	-0.43 +0.30	2266.4	2590.3	114.3	2336.6	2433.6	104.2	5023.9	109.1
Kapinga 1°N,155°E	NA NA	NA NA	1683.8	1251.5	74.3	1454.9	1752.9	120.5	3004.3	95.7
Kosrae 5°N,163°E	+0.27 +0.79	-0.64 +0.93	2567.9	2376.9	92.6	2342.9	2619.8	111.8	4996.7	101.8
Majuro 7°N,171°E	+0.23 +0.33	-0.31 +0.24	1368.3	1609.3	117.6	1868.2	2058.7	110.2	3668.0	113.3
Kwajalein 9°N,168°E	+0.26 +0.02	+0.09 -0.21	801.4	1231.4	153.7	1579.1	1791.7	113.5	3023.1	127.0

Micronesia have been rising for several decades at a rate that roughly matches the reported rise of global average temperature of +0.74°C in the last century. The temperature time series of Guam's Andersen Air Force Base (AAFB), Koror (Palau, western Micronesia, 7.3°N, 134.5°E), and Yap (Federated States of Micronesia, FSM, 9.5°N, 138.1°E) are coherent (Fig. 7.50), and generally follow the Northern Hemisphere temperature trend noted by the Hadley Climate Research Unit, but with larger interannual variation. Looking more closely at the long-term behavior of the temperature at AAFB (Fig. 7.51), the temperature peaked in the late 1990s, and has fallen slightly since then. The 2011 temperatures across Micronesia were mostly above the 1981–2010 averages, especially in the first half of the year (see Table 7.4), but were below the peak warmth seen in the late 1990s.

In the Pacific tropics, the attribution and causality of month-to-month and seasonal temperature anomalies are more difficult to identify than those for rainfall anomalies. Thus, most of the relatively small six-month temperature anomalies of 2011 as shown in Table 7.4 are not attributable to any discernible cause. The large anomalies seen in 2010 data did not reappear in the 2011 data. Thus, only a few locations and six-month periods are discussed for 2011.

While most of Micronesia was wetter than normal during the first six-month period (January–June), the warmer-than-normal maxT values at most locations suggest convective-type daytime rain where the temperatures rise rapidly during breaks between the showers. This was especially the case for Guam (+0.66°C) and for Chuuk (FSM, 7.4°N, 151.8°E; +0.80°C). The larger higher-than-normal minT anomaly seen at Kosrae (+0.79°C) suggests a rather long period of nighttime cloudiness and reduced radiational cooling. Guam's minT of +0.72°C likely reflects the higher daytime maxT.

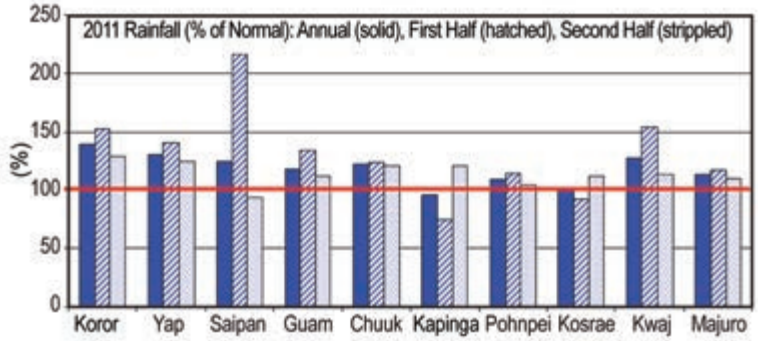

Fig. 7.52. Annual rainfall totals (% of normal) for selected locations on various Micronesian islands for 2011 (1981–2010 base period). Kapinga stands for Kapingamarangi Atoll in Pohnpei State, Federated States of Micronesia (FSM).

Temperatures from July to December were closer to normal than those during the first half of the year at most locations. MaxT anomalies for the six-month period (July-December) were generally cooler in the eastern part of the basin (see Table 7.4, Majuro, Kosrae, Pohnpei) and warmer in the western part. Kosrae had the largest reduction of range between the daytime and nighttime temperatures, with a July–Decemeber maxT of -0.64°C and a minT of +0.93°C. This suggests a rather long and persistent period of daytime and nighttime cloudiness, but limited cloud observations on Kosrae did not allow confirmation of this assumption. Temperature anomalies for the first six-month period and for the last six-month period for selected Micronesian locations are summarized in Table 7.4.

(iii) Precipitation

Micronesian precipitation during 2011 was fairly typical of a year that begins with a moderate-to-strong La Niña and ends with the reemergence of another La Niña event. The six-month and annual rainfall values for selected locations are summarized in Table 7.4. In the first half of the year, virtually all of Micronesia was considerably wetter than normal. Notable exceptions were the near-equatorial island of Kapinamarangi and its northern neighbor, Kosrae. In more western locations, Palau rainfall for January–June was a record-setting 152.4% of normal, while Yap was 140.4%, and the rainfall amounts at Guam and Saipan in the Mariana Islands were 134.6% and 215.8% of normal, respectively. Farther east, conditions poleward of 6°N were wet and those more equatorward were relatively dry. Thus, Chuuk and Pohnpei had rainfall values of 123.6% and 114.3% of normal, respectively, while locations nearer the equator, such as Kapingamarangi and Kosrae, had values that were 74.3% and 92.6% of their respective normal amounts. Finally, at the east end of the region in the Marshall Islands, Majuro had 117.6% normal rainfall and Kwajalein had 153.7% of normal.

During the last half of the year, many locations poleward of 6°N saw a 10–40% reduction in rainfall, while others had percentages similar to those in the first half. Locations equatorward of 6°N saw a 20–45% increase in rainfall. From west to east across Micronesia, compared with January–June anomalies, Palau rainfall decreased to 128.5% of normal, Yap rainfall decreased to 124.2%, Chuuk rainfall decreased only a few percent to 120.3%, and Pohnpei rainfall decreased to 104.2%. Farther east, Majuro rainfall decreased to 110.2% (-7.4%) and that at Kwajalien fell to 113.5%, a very large 40.2% reduction. Farther north, Guam rainfall decreased to 111.8% and that at Saipan plunged to 93.8% of normal.

Farther toward the equator, the rainfall percentage at Kosrae rose to 111.8% of normal, and at Kapingamarangi, it ascended to 120.5%. The latter location experienced a severe drought in 2010 that continued into 2011. While the January–February 2011 rainfall there was only 11.5% of normal, rains finally returned in March and continued to be above average thereafter.

For the most part throughout Micronesia, 2011 annual rainfall was wetter than normal. Figure 7.52 shows the annual rainfall amount and percent of normal for the major Micronesian islands. Of the major islands, annual rainfall amounts ranged from a high of 5229.4 mm at Koror, Palau, (139.4% of normal) to a low of 2209.8 mm at Saipan in the CNMI (124.7% of normal). In addition to Palau at the western edge of the area, Yap was also extremely wet with an annual rainfall of 4005.6 mm (130.4%). At the eastern edge of the area, Majuro was wet with 3668.0 mm (113.3% of normal) and Kwajalein had 3023.1 mm (127.0%).

In the central FSM, Chuuk ended the year with 4161.8 mm (121.8% of normal), Pohnpei had 5023.9 mm (109.1%) and Kosrae finished with 4996.7 mm (101.8% of normal). The north central island of Guam had 2933.0 mm (118.3% of normal) for the year. Only Kapingmarangi ended the year with a slight deficit, measuring 3004.3 mm or 95.7% of normal.

(iv) Notable events

A severe drought occurred at the start of the year at Kapingamarangi. Because La Niña produced cooler-than-normal sea surface temperatures along the equator for several months beginning in the latter part of 2010, the atolls of Pohnpei State located at low latitude (e.g., Kapingamarangi at 1°N and Nukuoro at 4°N) had reduced rainfall from July 2010 through early 2011. The low rainfall was most pronounced at Kapingamarangi where the rainfall during September 2010 through February 2011 was 180.9 mm. This level of dryness (only 15% of normal rainfall during the six-month period) prompted the Weather Forecast Office (WFO) in Guam to issue some eight months of weekly drought advisories for Kapingamarangi. Much needed rainfall finally occurred at the atoll in March 2011, and continued for the remainder of the year. Damage to trees and crops occurred during the long dry spell.

Another notable weather anomaly was high annual precipitation at many islands in Micronesia. Annual rainfall totals in excess of 120% of normal were experienced at locations in the Republic of Palau, Yap State, Guam, Saipan in the CNMI, and in Chuuk State. The 2011 annual rainfall at the Koror (Palau) Weather Service Office set a new record high. The 5228.8 mm of rainfall was the highest annual total in a period of record at Koror that extends back to 1948 and also contains a period of climatic record-keeping by the Japanese that covers the years 1932–37. The previous record-high annual total at Koror occurred during 1974 when 4698.7 mm was observed. The 2011 annual rainfall total was even higher at the Palau International Airport where the 5474.2 mm was the second-highest 2011 annual total seen in all of Micronesia. It was exceeded only slightly by the 5493.0 mm recorded at Palikir on Pohnpei Island. The PIA has only a short record that begins in 2004, but it is usually wetter there than at the Koror weather office located only a few miles to the southwest. There were a few rainfall events that caused minor mudslides on the island nation's largest island, Babeldaob.

High sea levels that prevailed in late 2010 continued into 2011 as a result of strong trade winds that increased the easterly wind stress, causing water to mound up in the west of the basin. This caused warm water to mix downward, increasing the oceanic volume and causing sea levels to remain high during the first third of the year. After La Niña peaked in late 2010, sea levels in Micronesia reached their highest values of 2011 in January and February. Average heights ranged from around +10 cm above normal at Kwajalein, Yap, Chuuk, and Guam to around +20 cm above normal at Majuro, Pohnpei, and Palau. Extreme values ranged from +50 cm at Guam to +115 cm at Majuro and Palau. Sea levels began to fall in the boreal summer across Micronesia as La Niña waned and gave way to ENSO-neutral conditions. Sea level values almost made it to normal, but the reemergence of La Niña strengthened the trade winds, and once again, water began to mound up in the western Pacific.

2) Australia—C. Ganter and S. Tobin

(i) Overview

For Australia, back-to-back La Niña events gave a two-year rainfall total for the 2010–11 period of 1408 mm, the wettest such period on record. This surpasses the previous Australian record of 1407 mm, set under sustained La Niña conditions during 1973 and 1974. The 2011 rainfall total was 51.6% above average—705 mm, Australia's second-wettest year since records commenced in 1900 (only 1974 was wetter, with 760 mm). As in 2010, 2011 saw numerous significant flood events throughout the year, some resulting in the loss of life.

For the first time since 2001, Australia's annual mean temperature was below the 1961–90 average. With an anomaly of -0.14°C, 2011 ranks near the median of observations since 1910. Cooler annual temperatures in Australia are commonly associated with years of widespread, high rainfall. Such a pattern of positive rainfall anomalies across vast areas of continental Australia is typical of La Niña years.

Heavy rainfall at the start and end of the year, and unusual southerly flow in the first half of the year, suppressed maximum temperatures over much of the mainland. Despite 2011's cool anomaly, the 10-year average for 2002–11 was the equal-warmest 10-year period on record for Australia (both 2002–11 and 2001–10 recorded an anomaly of +0.52°C).

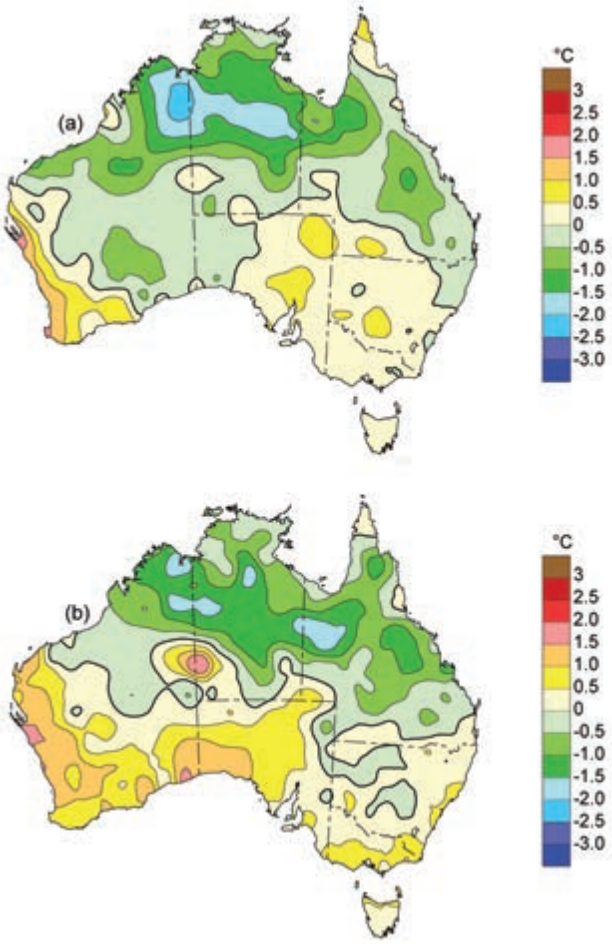

Fig. 7.53. (a) Australian mean annual maximum temperature anomalies (°C; 1961–90 base period) for 2011; (b) Australian mean annual minimum temperature anomalies (°C; 1961–90 base period) for 2011.

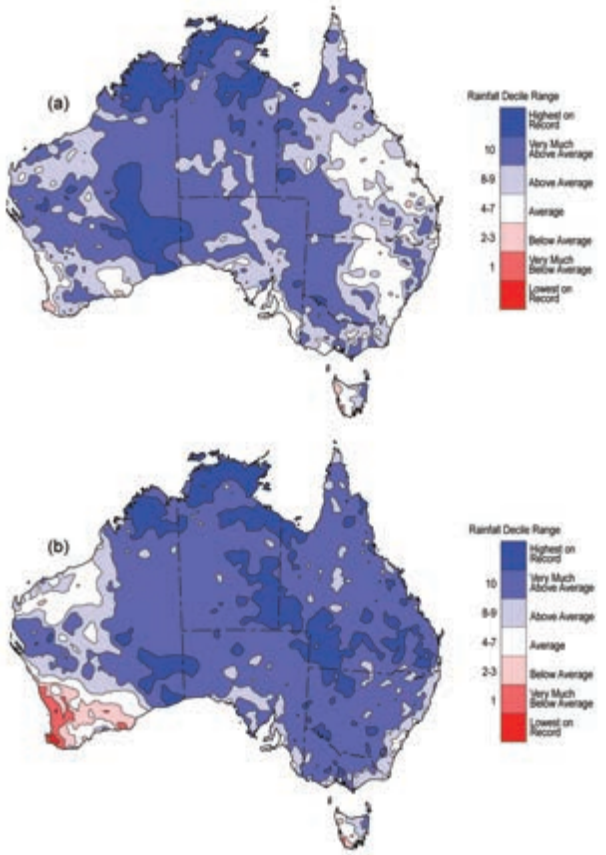

Fig. 7.54. (a) Australian annual rainfall deciles (since 1900) for 2011; (b) Australian annual rainfall deciles (since 1900) for the two-year period 2010–11.

(ii) Temperature

Even though 2011 was cooler than average nationally, only northern Australia experienced below-normal annual temperatures (both maxima and minima), while across the south, temperatures were above average. Overnight warmth was especially notable in parts of southern Western Australia and South Australia where annual average minimum temperatures were the highest on record. Annual average maxima and mean were also the highest on record along the lower west coast of Western Australia by a large margin. For Australia overall, the maximum temperature anomaly was -0.25°C, with minima at -0.03°C (Fig. 7.53).

January, July, and August temperatures were well above average for most of Australia, excluding the tropics. Despite being cool over much of Western Australia during February and March, both maxima and minima were highest on record for parts of the western coast in both months. Away from the eastern and western coastal strips, March was cooler than average for most of the country, with record-low March maxima and mean temperatures recorded in some regions of northern and southern Australia. Temperatures were very much below average during April, May, and June over northern Australia. June minima were lowest on record (departures of -4°C to -6°C) for a large area over northern Western Australia and the Northern Territory. July was warm through the southwest, and the most widespread positive anomalies occurred in August, with the majority of Australia south of the Tropic of Capricorn very much above average. For the remainder of the year, conditions were generally cooler than average over the tropics, but warmer than average over the more southern regions.

(iii) Precipitation

For the year as a whole, the majority of Australia received very-much-above-average rainfall (Fig. 7.54a). Large areas of record-high totals fell in the Kimberley, southeastern Western Australia, and across the north of the Northern Territory. It was the

wettest year on record for Western Australia and the third wettest for the Northern Territory. Most of the record precipitation fell during the summer months (DJF), and was associated with the Australian monsoon and associated systems across southern parts of the continent. This is consistent with the influence of the 2010/11 La Niña, one of the strongest on record.

Above-average rainfall fell across most of the continent during the first four months of 2011, before the La Niña decayed in autumn (MAM). January brought record-breaking rainfall to the west of both New South Wales and Victoria, and for Victoria, summer was the wettest on record. Rainfall was also above average for much of Western Australia, northern Australia, southeast Queensland, and Tasmania. Very heavy rainfall continued in February and March, though missing the northeast and far southwest in February, and much of Western Australia and parts of the southeastern states in March. As the La Niña decayed, April saw very-much-above-average rainfall in the Kimberley and Top End.

Continuing a trend observed over the past decade, rainfall across southern parts of the continent was below average from May through September in most regions.

La Niña conditions redeveloped during austral spring, with a second, weaker event accompanied by a return to above-average national rainfall. Very warm conditions across the Indian Ocean to the west of the continent were also favorable for increased rainfall over western and southern parts of Australia. October rainfall was very much above average in the north and west, with large areas of highest-on-record totals in southern inland Western Australia. November rainfall was generally very much above average, except for east coast Queensland and December saw above-average rainfall for much of the east and south of Australia.

(iv) Notable events

In the 2010/11 season, four tropical cyclones made landfall in Australia; Tasha, Anthony, Yasi, and Carlos. All cyclones contributed to flooding, and Yasi and Carlos caused significant wind damage. Carlos contributed to several record-breaking rainfall totals and flooding around Darwin in the Northern Territory, while Yasi was one of the strongest tropical cyclones to hit Queensland in almost a century, causing $1.3 billion (US dollars) in damage, according to the Insurance Council of Australia, Catastrophe Disaster Statistics (see http://www.insurancecouncil.com.au/IndustryStatisticsData/CatastropheDisasterStatistics/tabid/1572/Default.aspx). One of the more notable aspects of the 2010/11 cyclone season was the number of tropical depressions. At least 29 systems developed into tropical depressions between November 2010 and April 2011 in the Australian region, the most in a season since at least the mid-1990s (see section 4d7 for more detail).

Exceptionally cool overnight minima were experienced during May and June over northern Australia. Darwin minimum temperatures dropped below 20°C every night during June for the first time on record. In total, Darwin had 47 consecutive nights below 20°C, the fourth longest run in its record.

Between 9 and 11 July, damaging winds and waves were experienced along the west coast of Tasmania, a result of two strong cold fronts passing over the region. The wave-rider buoy at Cape Sorrell measured its highest wave on record, 18.68 m on the 11th, also the second highest wave ever recorded in the area.

During late January to early February, southern mainland Australia experienced a significant heatwave. Woomera, in South Australia, broke its highest daily temperature record, with 48.1°C on 25 January. Sydney experienced its longest hot spell in its 152-year record, with seven consecutive days above 30°C (31 January–6 February) and five nights above 24°C between 2 and 6 February. August brought unseasonable warmth, with Tasmania recording its warmest August on record. Western Australia's Pilbara region experienced a warm finish to the year. Between 20 and 22 December, numerous sites exceeded 45°C, with Roebourne Airport recording 49.4°C on 21 December, the highest Western Australian December value (and second highest Australia-wide), and the highest temperature anywhere in Australia since 1998.

(v) Significant statistics

- Mean annual maximum temperature anomaly: -0.25°C
- Mean annual minimum temperature anomaly: -0.03°C
- Mean annual rainfall anomaly: +52% (second highest since records began in 1900)
- Highest annual mean temperature: 28.4°C, Coconut Island (Queensland)
- Lowest annual mean temperature: 4.2°C, Thredbo (New South Wales)
- Highest annual total rainfall: 10 078 mm, Bellenden Ker Top Station (Queensland)

SIDEBAR 7.4: AUSTRALIA'S WETTEST TWO-YEAR PERIOD—C. GANTER AND S. TOBIN

Australia experienced flooding and heavy rainfall across many regions during 2010 and 2011, an effect of strong La Niña conditions. This exceptionally heavy rainfall resulted in the wettest two-year period on record, with 1408 mm. This was the wettest of any 24-month period, nudging out the calendar years of 1973 and 1974 which had 1407 mm. During 2010–11, most of Australia received rainfall in the highest decile (see Fig. 7.54b).

The spring and summer months from September 2010 to March 2011 were exceptionally wet, associated with a very active monsoon season. Individual months of note include September and December 2010, and March 2011, all record-wettest for their respective months, as well as October 2010 and February 2011, which were second wettest. February and March 2011 recorded the fifth- and third-highest rainfall for any month, respectively.

From September 2010, flooding events were commonplace. Heavy rainfall at the start of 2011 resulted in some of the most significant flooding, in terms of extent, impact, and severity, in Australia's recorded history.

One of the most significant flood events occurred in southeast Queensland and adjacent northern New South Wales. During the second week of January, severe river and flash flooding affected the Brisbane River catchment and Toowoomba/Lockyer Valley, resulting in Brisbane's second highest flood level in 100 years (after January 1974). Farther south, exceptional rain from complex and persistent low pressure systems caused flash flooding across western and central Victoria, and northern Tasmania. Parts of northeast and western New South Wales were also affected. Rainfall of 100 mm–300 mm occurred across much of northern Tasmania and large parts of Victoria.

Victorians were again subject to heavy rainfall and flooding in early February, from thunderstorms associated with ex-Tropical Cyclone Anthony.

March 2011, the wettest month for Australia since January 1984, brought extensive flooding to the eastern Kimberley region in Western Australia resulting from a monsoonal burst. In late March, storm cells brought further flooding to northeast Tasmania (some sites received five times their usual March rainfall), as well as the New South Wales southeast coast and the far east of Victoria.

The high rainfall brought abundant growth to the usually arid center of Australia during 2010–11. In places, this growth was waist high, and estimates placed the vegetation at levels not seen since 1974. Fires are commonplace during the northern Australian dry season, as grasses dry and cure. The subsequent fire season (August–October) saw the most widespread grass and scrub fires since 1974—mostly the result of lightning strikes—occur over central and northern Australia. In September alone, an area larger than Tasmania (approximately 1 500 000 ha) was burnt around Alice Springs in central Australia.

- Highest temperature: 49.4°C, Roebourne (Western Australia), 21 December—a new December state record
- Lowest temperature: -16.0°C, Charlotte Pass (New South Wales), 27 July
- Highest one-day rainfall: 477 mm, Mornington Island (Queensland), 1 March
- Highest wind speed (measured): 206 km hr^{-1}, Willis Island (Queensland), 2 February (Tropical Cyclone Yasi)

3) New Zealand—G. M. Griffiths

(i) Overview

Annual mean sea-level pressures were much higher than usual well to the east of the North Island in 2011, producing more northeasterly winds than usual over northern and central New Zealand. This circulation anomaly over the New Zealand region is typical of La Niña. The large-scale climate setting was primarily driven by a moderate-to-strong La Niña event at the start of 2011, which eased to neutral in (austral) winter (JJA), but redeveloped to moderate levels during spring (SON). The anomalous northeasterly winds resulted in above-average annual temperatures and well-above-normal annual rainfall, for the northeast North Island and the north of the South Island.

The year 2011 will be remembered as one of extremes for New Zealand. Subtropical lows during January produced record-breaking rainfalls. New Zealand experienced exceptional heat during the first half of February. Winter arrived extremely late—May was the warmest on record, and June was third warmest. In contrast, two significant snowfall events in late July and mid-August affected large areas of New Zealand, with snow lying to unusually low elevations and extremely low air temperatures experienced. Lastly, torrential rainfall in the north of the South Island caused a State of Emergency to be declared on 14 December, following record-breaking rainfall, widespread flooding, and landslides. Takaka recorded 392 mm of rainfall in 24 hours during this event, the highest 1-day rainfall observed in New Zealand during 2011.

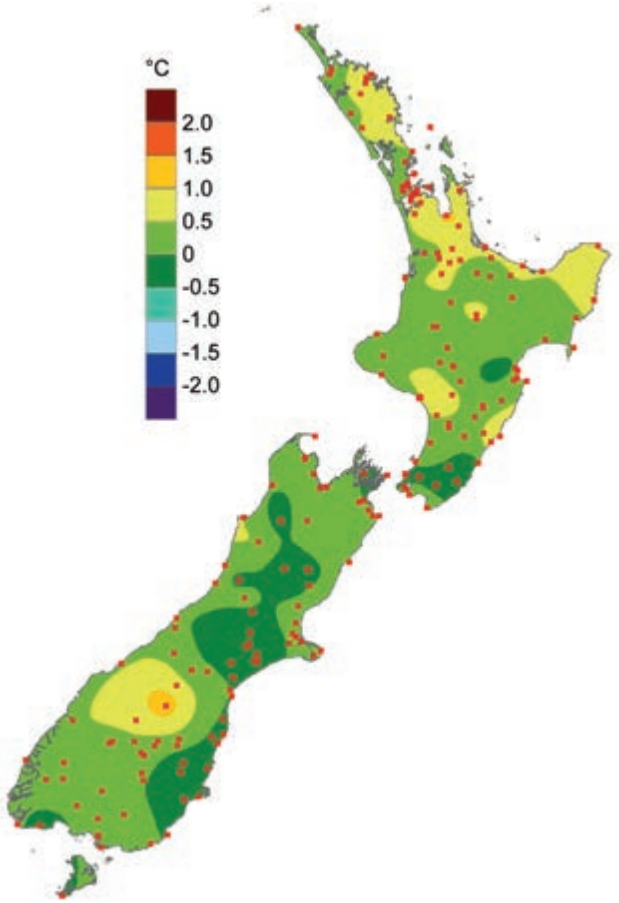

Fig. 7.55. Mean annual temperature anomalies (°C) over New Zealand for 2011.

In the following discussion, the base period is 1971–2000 for all variables. The New Zealand national temperature is based upon a seven-station record (see http://www.niwa.co.nz/our-science/climate/information-and-resources/nz-temp-record/seven-station-series-temperature-data).

(ii) Temperature

Mean annual temperatures (Fig. 7.55) were above the long-term average (+0.5°C to +1.2°C) in the northeast of the North Island, and over the north of the South Island. Mean annual temperatures were generally near average (within 0.5°C of average) elsewhere. It was the warmest year on record at Kerikeri (Northland) and Te Puke (Bay of Plenty).

The nationwide average temperature for 2011 was 12.8°C, 0.3°C above the 1971–2000 annual average, the 17th warmest on record, using NIWA's seven-station temperature series which begins in 1909. It was notable for six warm months (January, February, May, June, October, and December) and three cold months (April, August, and September).

Record-breaking high temperatures (and humidity) were experienced over much of the North Island on 18 and 19 January, as tropical air was delivered to the country by ex-tropical cyclones Vania and Zelia. The entire country was affected by scorching temperatures between 2 and 7 February, as long-fetch northwest winds became slow-moving over New Zealand. Timaru recorded 41.3°C on 6 February, a new all-time record in the area since records began in 1885. Many sites recorded temperatures in excess of 30.0°C during 5 and 6 February. Unusually, the heat continued into April and May on occasion, with easterly winds contributing to temperatures of 28.4°C at Westport on 26 April, and a heat wave on the West Coast of the South Island and in Nelson on 1 May.

In contrast, the snowfall events 24–26 July and 15–16 August delivered exceptionally cold conditions to New Zealand, with numerous all-time low temperature records broken.

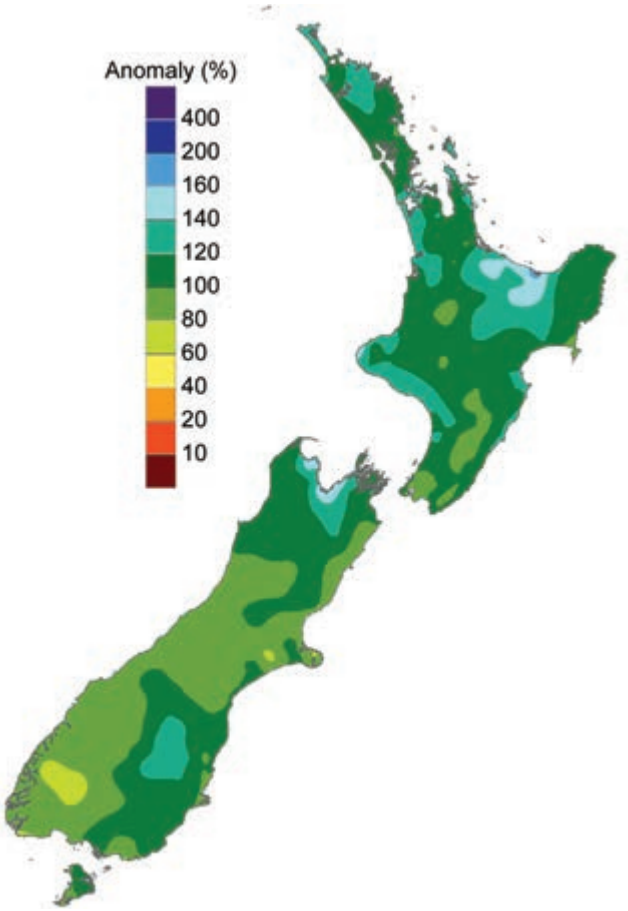

Fig. 7.56. Mean annual precipitation anomalies (%) over New Zealand for 2011.

(iii) Precipitation

In broad terms, six months of the year were wetter than normal and two were drier than normal (August and September). Four months were mixed, with large geographical differences between very wet regions and areas of extreme dryness. Annual rainfall totals for 2011 (Fig. 7.56) were above normal (more than 120% of normal) in parts of Northland, Auckland, Coromandel, Bay of Plenty, Nelson, and Central Otago, as well as around New Plymouth, Napier, Wanganui, and Palmerston North. In contrast, it was a relatively dry year (with annual rainfall totals 50–79% of normal) for the Kaikoura Coast and Canterbury, as well as much of Fiordland and Westland. Elsewhere, annual rainfall was in the near-normal range (80–119% of normal).

The wettest place in 2011 was Cropp River, in the Hokitika River catchment (West Coast) which recorded an annual rainfall total of 9493 mm. The driest of the available reporting locations was Clyde (Central Otago), which recorded 395 mm of rainfall in 2011.

Soil moisture deficits in 2011 were generally short-lived. At the beginning of 2011, significant soil moisture deficits of more than 110 mm affected parts of western Northland, Waikato, Bay of Plenty, Gisborne, Manawatu, and Wairarapa, as well as parts of Canterbury and Central Otago. However, the extremely wet January in all North Island regions fully recharged soil moisture levels, and rainfall in March and April replenished all remaining dry soils in the South Island. August and September were relatively dry, and by the end of November, significant soil moisture deficits were observed in regions north of Taupo, as well as Hawkes Bay, Gisborne, Marlborough, and central Otago. Above-normal rainfall totals in December throughout the North Island improved soil moisture levels there, but deficits had become extreme (more than 130 mm of deficit) in Central Otago and parts of Southland by the end of 2011.

(iv) Notable events

Two significant snowfall events occurred in 2011. A polar blast during 24–26 July delivered a bitterly cold air mass over the country. Snowfall was heavy and reached low elevations over Canterbury, the Kaikoura Ranges, the Richmond, Tararua, and Rimutaka Ranges, the Central Plateau, and around Mt. Egmont. Brief dustings of snow were also reported in the ranges of Motueka and Northland. During the event, snow closed major roads, businesses, public transportation services, airports, and schools, and the weight of the snow on power lines caused outages.

During 14–17 August, a second polar outbreak brought heavy snow to unusually low elevations across eastern and alpine areas of the South Island, as well as to suburban Wellington. On 14 August, snow fell to very low elevations across much of the South Island, as well as in central Wellington and the hill suburbs. On 15 August, the southerly winds continued to deliver extremely cold air and snowfalls to the country, and airports and schools remained closed in Christchurch, Queenstown, Invercargill, and Dunedin. On the West Coast, snow fell in Rotomanu, Inchbonnie, Reefton, Greymouth, Blackball, and Ikamatua. Snow fell again to sea level in Wellington, closing schools and Wellington Airport. Both Rotorua and New Plymouth reported snow falling in the central city. Snow fell briefly in Auckland city but did not settle, and was also reported from the Waitakere Ranges, Drury, Waiuku, Clevedon, and the Bombay Hills. The snow reached Northland, with hillside properties around Dargaville reporting snow falling. Taupo Airport was also closed as heavy snow fell around the lake. In the Waikato, snow was seen in central Hamilton (the first time since August 1980), Te Kuiti, and briefly in Raglan. Snow settled in Wanganui, reportedly for the first time since 1974. Between 15 and 17 August, many eastern and alpine South Island roads, as well as lower North Island roads, were affected by snow or ice, and airports, hospitals, mail deliveries, and power lines were impacted in these regions.

On 14 December, heavy rain caused severe landslides and flooding in Nelson and Golden Bay. A State of Emergency was declared. Takaka recorded 392 mm of rainfall in 24 hours, a new record there, and the highest 1-day rainfall observed in New Zealand in 2011. In Nelson city, the Matai river walkway was closed by flooding, as were many urban and rural roads, isolating communities. More than 100 homes near rising rivers were evacuated. The Coastal Highway was closed at both Appleby Bridge and at Takaka Hill. The community of Collingwood was cut off after the road was washed away, and roads to Pakawau and Puponga were closed. A dam collapsed above Pohara Gully in Golden Bay, and on 15 December, schools in that region were closed after the extreme rainfall closed roads and damaged property. Many landslides threatened properties in the Nelson region, and more homes were evacuated. Many roads in Nelson, Waimea, and Golden Bay remained closed on 16 December, including between Takaka and Collingwood.

(v) Significant statistics

- The highest recorded temperature was 41.3°C, observed at Timaru on 6 February (a new all-time high temperature record there).
- The lowest recorded air temperature was -10.2°C, recorded at Manapouri on 26 July (a new all-time low temperature record there).
- Of the regularly reporting gauges, Cropp River in the Hokitika River catchment (West Coast) recorded the highest annual rainfall total, with 9493 mm.
- The driest of the available reporting locations was Clyde (Central Otago), which recorded 395 mm of annual rainfall.
- Takaka experienced the highest 1-day rainfall (392 mm), recorded on 14 December (a new all-time daily rainfall record there).
- Nelson was the sunniest location in New Zealand, recording 2487 hours.
- The highest recorded wind gust was 189 km hr^{-1} at Cape Turnagain on 12 July.

Libraries: Please file with the *Bulletin of the American Meteorological Society*, Vol. 93, Issue 7