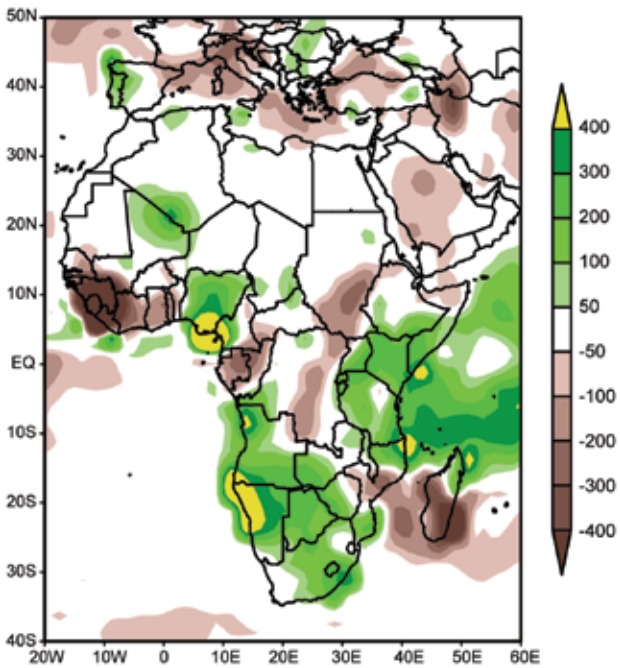

Fig. 6.1. African 2006 annual precipitation anomalies (mm; 1979–2000 base) from the CAMS-OPI dataset (Janowiak and Xie 1999). [Source: NOAA/NCDC.]

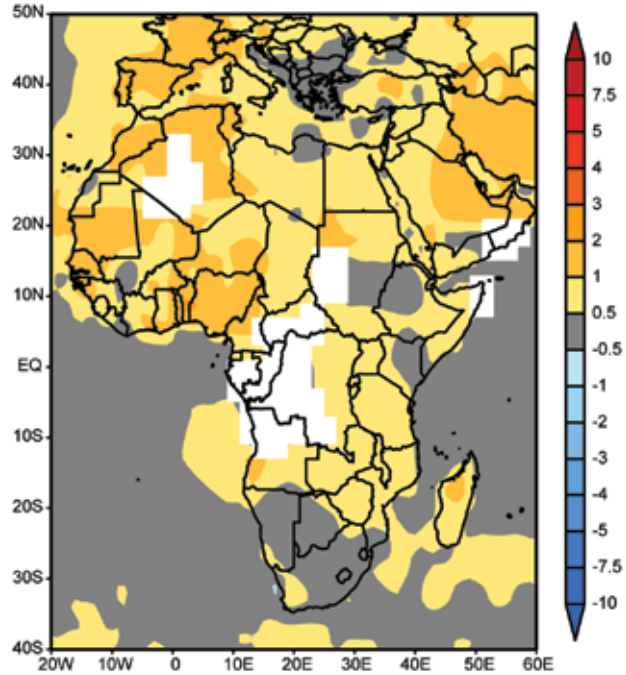

Fig. 6.2. African 2006 annual temperature anomalies (°C; 1971–2000 base) from CAMS-OPI.

decrease in Antarctic ozone depletion beginning around 2010, detectable at the 2σ level by 2023, and with a disappearance of the springtime ozone depletion phenomenon by 2070.

6. REGIONAL CLIMATES—A. Arguez, Ed.

a. Overview—A. Arguez

While a holistic (global) view of the 2006 state of the climate is a worthwhile vantage point, much can also be gleaned by analyzing individual continents, countries, and subregions. This section represents such a "downscaling" approach, as 2006 weather conditions over smaller geographic areas are not only described and put in a historical context, but international and interregional contrasts are also brought to light. The section is divided into seven sections: Africa, North America, Central America and the Caribbean, South America, Asia, Europe, and Oceania. These regions are further subdivided into practical climate divisions. Country and regional names utilized in this section do not, in any shape or form, reflect any political bias or sympathy. In addition, please note that varying base periods are often utilized for the computation of climate anomalies.

b. Africa—A. Arguez

Precipitation was generally above average over much of Sub-Saharan Africa in 2006 (Fig. 6.1). Several flood events and droughts occurred, causing substantial losses to human life and property. Most of Africa was slightly warmer than average for 2006 (Fig. 6.2). The following section discusses the state of the climate in four distinct regions: eastern Africa, northern Africa, southern Africa, and western Africa (including the Sahel).

1) Eastern Africa—M. Bell, C. Oludhe, P. Ambenje, L. Njau, Z. Mumba, and M. Kadi

The GHA countries have experienced heavy rainfall leading to severe flooding (the worst in the region for 50 years), causing loss of life and property in the region from October to November 2006. The worst hit were parts in Ethiopia, Somalia, and Kenya. Flood waters from the Juba River in Somalia and the Tana River in Kenya combined to inundate a large region of northeastern Kenya. Several rivers burst their banks, washing away roads and destroying bridges.

Climatologically, the timing of the rainy seasons in East Africa is governed by the meridional migration of the ITCZ through the course of the year. Although the complex orography and presence of the East African lakes make the climate of the region quite complicated, three general regimes can be delineated. In the southern sector, central and southern Tanzania has a unimodal rainfall regime, with precipitation primarily between December and April.

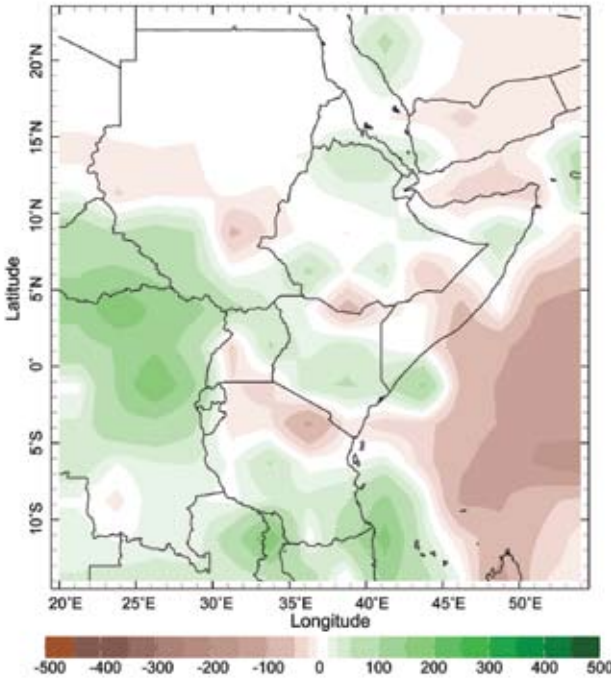

Fig. 6.3. March–May 2006 precipitation anomalies (mm; 1979–2000 base) for East Africa using CMAP (Xie and Arkin 1997), v0610. [Source: NOAA/CPC.]

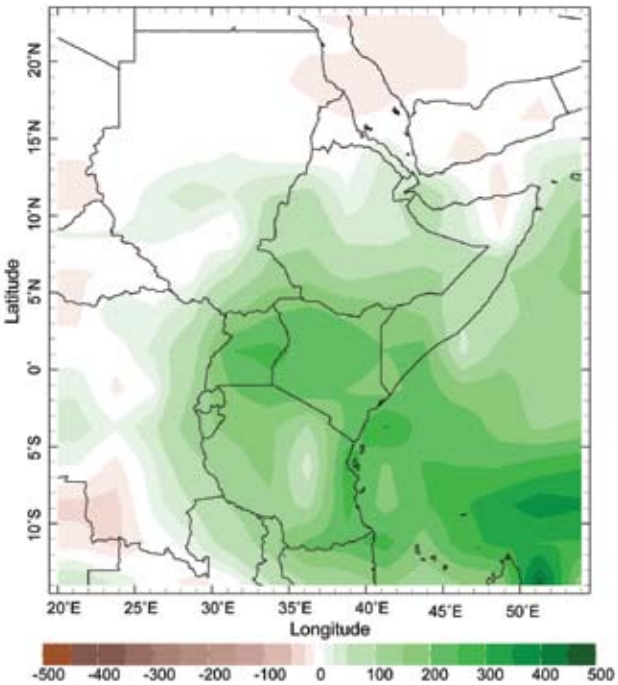

Fig. 6.4. October–December 2006 precipitation anomalies (mm; 1979–2000 base) for East Africa from CAMS-OPI.

Northern and northeastern Tanzania, most of Kenya, southern and eastern Ethiopia, and most of Somalia comprise the equatorial sector, which generally exhibits a bimodal rainfall regime, with the "long rains" during March–May and the "short rains" during October–December. In the northern sector, which includes much of central and western Ethiopia, western Eritrea, and much of Sudan, the major rainy season occurs during the months of June–September. In addition to a peak in rainfall centered on July and August, areas of north-central Ethiopia, eastern Eritrea, and Djibouti also experience a climatological rainfall maximum during March–May.

East Africa experienced a dramatic shift from terrible drought at the beginning of the year to generally abundant precipitation that was accompanied by destructive flooding throughout the region. Although the March–May long rains (Fig. 6.3) brought above-normal rainfall to parts of Kenya and southern Somalia, areas of northern Tanzania, and portions of northern Kenya, southern and eastern Ethiopia, and central Somalia continued to experience precipitation deficits. However, the October–December short rains (Fig. 6.4) produced above-normal rainfall throughout the region.

(i) Southern sector

By the early months of 2006, below-normal rainfall in Tanzania during the previous year was causing significant food security and power supply problems. Approximately two-thirds of Tanzania's electrical power is produced by hydropower. By February 2006, water levels in the country's hydropower reservoirs were nearly too low to continue producing electricity. After extremely dry conditions in January, rain finally began falling somewhat consistently in February and March in central and southern Tanzania, which constituted a delay of several weeks for the start of the rainy season there.

In the final quarter of 2006, some significant early rainy season precipitation fell in October and November in central and southern Tanzania, and rainfall in December was well above average throughout the country. The heavy rains caused flooding in the regions of Shinyanga and Kigoma in northwestern Tanzania. The paths of Tropical Storm Anita and Cyclone Bondo brought them into the northern end of the Mozambique Channel during December, providing an additional source of moisture and rainfall, though neither made landfall on the continent.

(ii) Equatorial sector

The extreme drought in East Africa, which became very severe by early 2006 with the nearly complete failure of the October–December 2005 short rains (Oludhe et al. 2006), was centered on the border re-

gion of northeastern Kenya, southeastern Ethiopia, and southern Somalia. Accumulated precipitation anomalies over the March–May 2006 long-rains season show near- to above-normal precipitation throughout much of Kenya, far southern Somalia, northeastern Uganda, and parts of southern Ethiopia. Below-normal precipitation is indicated in parts of north-central Kenya, southern Uganda, north-central Tanzania, eastern Ethiopia, and large parts of central and southern Somalia. Precipitation during the March–May long rains was only about 40%–70% of normal in these areas of Somalia (and in the neighboring Somali region of eastern Ethiopia, and parts of northern Kenya).

(iii) Northern sector

Rainfall in the highlands of central and western Ethiopia, much of Sudan, and western Eritrea started earlier than normal and remained plentiful throughout the June–September rainy season. In many areas of the northern sector, precipitation was more than 200% of normal. Heavy rainfall in July and August throughout most of Ethiopia resulted in deadly floods. In spite of some flood damage to crops, the above-normal June–September rainy season resulted in excellent crop production in Ethiopia and Sudan. A record cereal crop for 2006, estimated to be about 32% above the previous 5-year average, was forecast for Sudan.

2) Northern Africa—M. Bell

(i) Temperature

During 2006, annual mean temperature anomalies ranged from about 0.5° to 1.9°C above normal for most stations in North Africa. The warmest departures from the 1971–2000 mean were generally found along or just north of the Atlas Mountains across northern Morocco, Algeria, and Tunisia. Temperatures were generally cooler than normal in January and February 2006. Above-average temperatures returned to the region during March–May, but moderated somewhat during the course of the boreal summer through September. Above-normal temperatures again dominated in October and November.

(ii) Precipitation

The Mediterranean and Atlantic coastal area of North Africa receives the majority of its precipitation during October–April, largely from midlatitude cyclones and associated cold fronts. Mean annual rainfall totals decreased rapidly from about 700 mm at stations along the Mediterranean coast of Algeria and Tunisia to nearly zero in the interior of the Sahara Desert. In the Atlas Mountains of northern Morocco, Algeria, and Tunisia, cold-frontal passages can bring subfreezing temperatures and heavy rain or snow, occasionally causing floods and landslides.

For the year, annual precipitation amounts were above the 1971–2000 normal in a band extending just south of the Atlas Mountains from western Algeria northeastward into Tunisia, and at some locations along the Atlantic and Mediterranean coasts of Morocco and Algeria. Annual totals were generally below normal in Egypt, in interior Algeria, and in the Atlas Mountains of northern Algeria. Precipitation anomalies for the October 2005–April 2006 rainy season were above normal throughout the Canary Islands, Morocco, northern Algeria, northern Tunisia, and northwestern Libya. They were below normal in central Algeria, northwestern Libya, and northern Egypt

COUNTRY SPOTLIGHT: MOROCCO—K. Kabidi

During early 2006, Morocco recorded wet conditions with an average monthly rainfall much greater than the monthly long-term mean. Winter storm systems occurred during January and February, generating cold-air intrusion from the north and caused heavy rainfall that exceeded the monthly mean by more than 100%. For example, Rabat City recorded 173 mm during January, whereas the 1971–2000 monthly mean is only 82 mm. Several heat wave events occurred in late spring and during summer, punctuated by a +3°C temperature anomaly for the month of May in many parts of Morocco (Fig. 6.5). In addition, 2006 saw many Moroccan stations break wind speed records in summer, surpassing 100 km h^{-1} in some instances.

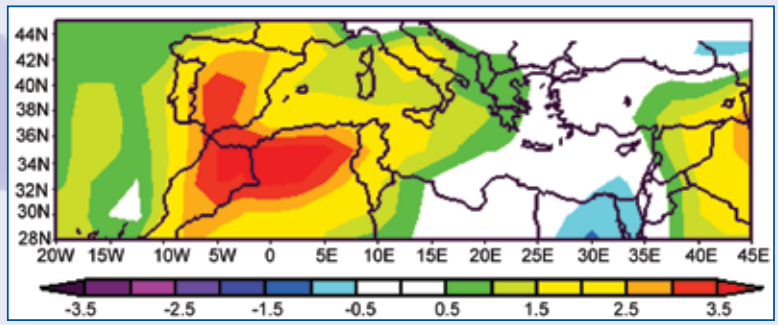

Fig. 6.5. May air temperature anomalies over northwest Africa (°C).

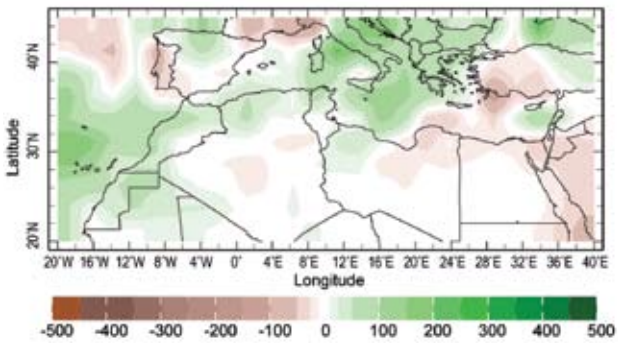

Fig. 6.6. October 2005–April 2006 precipitation anomalies (mm; 1979–2000 base) for North Africa from CMAP.

(Fig. 6.6). After generally near-normal precipitation during October–December 2005, several extratropical cyclones brought abundant rainfall to most of North Africa during the first two months of 2006. However, the months of March and April were quite dry throughout the region, particularly in northern Algeria and Tunisia. To start the 2006/07 boreal winter rainy season, precipitation deficits affected northern Morocco, Algeria, and Tunisia in October and November. Above-normal precipitation returned to northern Algeria and Tunisia in December.

(iii) Notable events

During 7–13 February, a slowly propagating extratropical cyclone tracked eastward across the Canary Islands and Morocco, and into western Algeria, producing unusually heavy rainfall and destructive flooding. The heavy rains at Las Palmas/Gando Station on the Canary Islands contributed significantly to an October 2005–April 2006 precipitation total that was approximately 200% of the median for the rainy season. The storm also contributed heavily to a February 2006 total of 81 mm of precipitation at Tindouf Station in western Algeria; mean and median rainfall for February are 2.7 and 0.6 mm, respectively.

3) Southern Africa—A. Kruger, W. Landman, and W. Thiaw

(i) Temperature

Annual mean temperatures over southern Africa were generally very close to the 1971–2000 mean in the southern parts, but about 0.5°–1.0°C above the 1979–2000 average in the north. In an area in the northern part of Madagascar, temperatures were between 1° and 2°C above normal (Fig. 6.2). The near-normal temperature conditions in the southern parts is reflected by the mean temperature anomalies of 28 South African climate stations, which show that temperatures in South Africa were about 0.27°C above the 1961–90 mean, making 2006 only the 15th warmest year since 1961.

(ii) Precipitation

Overall, southern Africa received mostly normal to above-normal rainfall during 2006. The Namibian northern coastal area and adjacent interior experienced very high rainfall, which is very uncharacteristic of the region. In contrast, below-normal rainfall was experienced in central Mozambique and central and southern Madagascar, where it was very dry in the east (Fig. 6.1).

The rainy season for most of southern Africa extends from October to April, with most rainfall usually from December to March. ENSO plays a significant role in the variability of rainfall, and for the most part causes drier conditions during warm episodes and wetter conditions during cold episodes. In the 2006 late-summer rainfall season, SSTs in the Niño-3.4 region were on average about −0.7°C below normal (base period 1971–2000), probably playing a role in the above-normal rainfall experienced over most of southern Africa during late summer.

A surface trough got established over southern Angola, Namibia, and South Africa. Associated with this system, upper-air (500 hPa) cyclonic circulation resulted in high rainfall totals during the austral summer and autumn over the southern parts, including South Africa, Namibia, Botswana, and Angola. Such wet conditions may have been associated with the La Niña conditions observed during early 2006. Well-established cloud bands were reported, contributing to large rainfall anomalies, particularly over Namibia. Easterly waves contributed to rainfall over the eastern regions including Kenia, Tanzania, Mozambique, and parts of South Africa. In late autumn, the surface circulation became anticyclonic, but with some frontal activity that contributed to anomalously wet conditions over parts of South Africa, including regions that are predominantly summer rainfall areas. During austral spring (SON), surface and associated upper-air trough systems developed once again over the west, leading to wet conditions over large areas of the region. However, these systems weakened during the month of December in association with the establishment of El Niño, associate with dryness over the south and wetter conditions over eastern equatorial Africa.

(iii) Circulation

The low-level atmospheric circulation associated

COUNTRY SPOTLIGHT: MOZAMBIQUE—D. Patricio

Mozambique is situated on the southern part of the East African coast, generally between 10° and 27°S and between 30° and 41°E. The country has a climate with tropical characteristics due to its location, with a hot rainy season generally from October to April, and a milder dry season from May to September.

In the southern part of Mozambique, the average monthly rainfall ranges from 23 mm in August to 152 mm in January. The annual average rainfall is about 857 mm. The monthly normal average air temperature ranges from 18.7°C in July to 26.3°C in February, with an annual average air temperature of 23.0°C. In 2006, the minimum monthly rainfall was observed in July (14.4 mm) and the maximum in March (289.0 mm), with an annual total of 1067.1 mm (24.5% above normal). Concerning the average air temperature, the smallest monthly average was 20.1°C in July and the largest was 27.8°C in February. The annual average value was 23.8°C, corresponding to 0.8°C above normal.

In central Mozambique, the monthly mean rainfall varies from 16 mm in September to 221 mm in February, with average annual rainfall of about 1191 mm (Fig. 8). The monthly average air temperature ranges from 20.2°C in July to 27.0°C in January; the annual average air temperature is 24.4°C. In the case of 2006, the minimum monthly rainfall was observed in July (5.4 mm) and the maximum in March (322.7 mm), with an annual value of 919.5 mm (22.8% below normal). With regard to the average air temperature, the monthly minimum value was registered as 21.1°C in July and the maximum was 29.2°C in December. The annual average value of 25.4°C corresponds to 1.0°C above normal.

In northern Mozambique, the monthly mean rainfall ranges from 4 mm in September to 196 mm in January; the annual average rainfall is about 1017 mm. The normal monthly average air temperature ranges from 19.4°C in July to 24.4°C in November; the annual average air temperature is 22.5°C. For 2006, the smallest monthly rainfall was observed in September (2.4 mm), while the maximum was reported in March (259.9 mm). The annual total was 1122.3 mm (10.4% above normal). The coldest (warmest) monthly average temperature was registered as 20.8°C (28.0) in July (November). The annual average temperature was 24.5°C (2.0°C above normal).

Figure 6.7 depicts the temporal distribution of monthly total rainfall and average air temperature for year 2006, as well as for the normal period (1961–90). In 2006, the weather was strongly influenced by the ITCZ during summer in the center and north. In the south, cold fronts played a dominant role. The southern and central parts of Mozambique were affected by a tropical depression in January, and by tropical cyclone Boloetse in February.

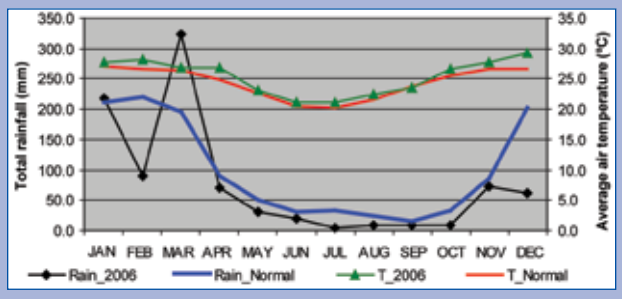

Fig. 6.7. Time Series of monthly total rainfall (mm) and average air temperature (°C) for Mozambique in 2006 and the normals for the 1961–90 base period.

with the 2005/06 rainy season featured easterly winds that averaged about 4–8 m s^{-1} from the east-central Indian Ocean westward into Madagascar and portions of interior southern Africa. This easterly flow was found along the equatorward flank of an enhanced Mascarene high pressure system and converged over interior southern Africa with a northeasterly flow that originated from the Bay of Bengal. The 500-hPa geopotential height exhibited strong intraseasonal variability in the circulation, but the presence of an anomalous trough was evident throughout the season. This anomalous trough was associated with a weak low-level anomalous cyclonic circulation across southern Africa and favored the intrusion of midlatitude disturbances. These contributed to higher-than-normal rainfall activity across southern Africa.

4) Western Africa—W. Thiaw

(i) Precipitation

The 2006 rainy season once again featured above-normal rainfall across most of the Sahel (Fig. 6.8). Rainfall totals were slightly less than those in 2005, but exceeded 100 mm above the average over portions of southwestern Senegal, southern and northern Burkina Faso, southern Niger, and central Chad. Overall, the 2006 rainy season was the fourth wettest since 1968. However, despite the wet conditions, the rainfall season was marked by a late onset. As of July, most areas in central Senegal, southern Mauritania, western Mali, and Niger reported rainfall deficits with amounts only 50%–70% of the long-term climatological mean. An abrupt northward jump of the ITCZ in mid-July marked the onset of the rains in most areas in the Sahel. As of August 2006, cu-

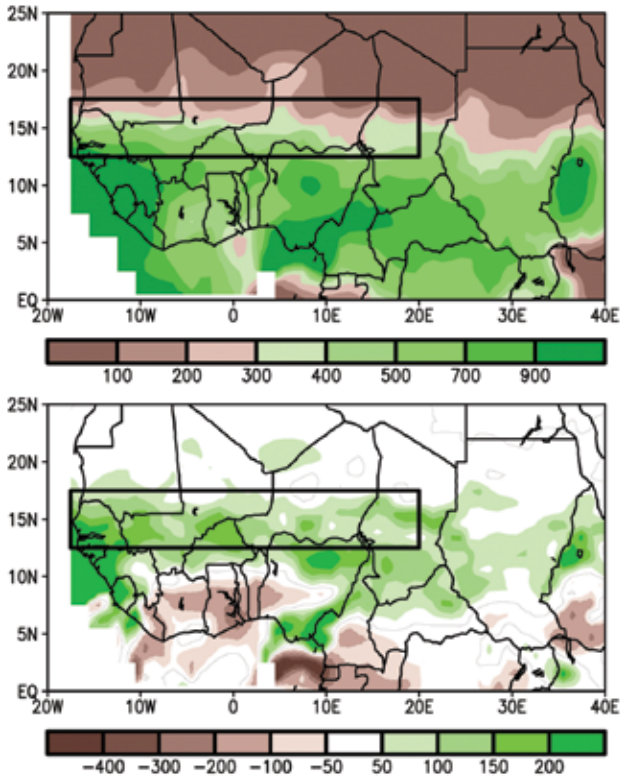

Fig. 6.8. June–September 2006 (a) total rainfall and (b) anomalies (mm; 1971–2000 base) for western Africa. The boxed region denotes the approximate boundaries of the Sahel.

mulative rainfall totals were near or above average across many areas in the Sahel. In the west, the formation of tropical depressions (some of them later developed into Atlantic tropical storms and hurricanes) along the coastlines of southern Senegal and Guinea, resulted in strong rainfall anomalies exceeding 200 mm. In contrast, seasonal rainfall totals across most of the Gulf of Guinea region were below normal. Rainfall deficits ranged between 100 and 300 mm across the central and southern areas of Benin, Togo, Ghana, most of the Cote d'Ivoire, and the eastern half of Guinea. The exceptions were the northern and southeastern areas of Nigeria, Liberia, and Sierra Leone, where rainfall totals exceeded 900 mm.

(ii) Atmospheric circulation

The above-average 2006 rainy season resulted from an enhanced West African monsoon in the latter part of the season. In August–September 2006, strong southwesterly winds at 925 hPa averaging 3–6 m s^{-1} extended well northward into the Sahel region. This enhanced monsoonal inflow was also evident at 850 hPa with Atlantic westerly wind anomalies exceeding 3 m s^{-1}, contributing to a deep penetration of moist, unstable air well into the Sahel region. The enhanced monsoon was also associated with an anomalous low-level cyclonic circulation across the northern and central Sahel, characterized by enhanced cyclonic shear along the equatorward flank of the AEJ. The mean position of the AEJ across the western Sahel was at about 15°N.

c. North America

1) Canada—R. Whitewood and D. Phillips

The climate of Canada in 2006 was characterized by near-record temperatures (Fig. 6.9) and near-normal precipitation relative to the 1951–80 base period (Fig. 6.10). Extreme weather took a toll this year with several deaths and millions of dollars in property damage. British Columbia suffered the most in 2006, starting the year with a near-record number of days with precipitation, experiencing drought-like conditions through the summer, and concluding with some of the most powerful storms ever to hit the province.

(i) Temperature

Canada, as a whole, experienced its second warmest year—2.4°C above normal (Fig. 6.11), with 1998 remaining the warmest at 2.5°C above normal—since reliable nationwide records started in 1948. Most of Canada had temperatures at least 2°C above normal, with the northern territories experiencing the greatest anomaly of about 4°C. Only an area in northern British Columbia had near-normal temperatures. This marks the 10th straight year of above-normal temperatures, with 6 of the warmest 10 years occurring in the last 10 years. Over the period of record (1948–2006) the national trend is +1.3°C.

Nine of the eleven Canadian climate regions had temperatures that ranked among the 10 warmest, with three climate regions having their warmest year: two covering Nunavut (+3.4° and +2.3°C), and one covering northern Ontario and Quebec (+2.3°C). Three other regions experienced their second warmest year: the region covering much of the Northwest Territories (+3.2°C), Atlantic Canada (+1.8°C), and southern Ontario and Quebec (+1.8°C). Over the 59 years of record, all the climate regions show a positive trend, with the region covering much of the Northwest Territories showing the largest trend of +2.2°C, and the Atlantic Canada region the smallest trend of +0.3°C.

(ii) Precipitation

Nationally, 2006 was unremarkable with regard to precipitation totals, ranking 21st wettest, out of

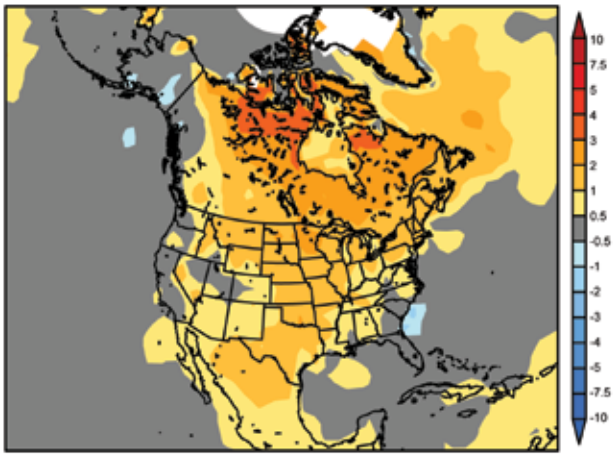

Fig. 6.9. North American 2006 annual temperature anomalies (°C, 1971–2000 base) from CAMS-OPI.

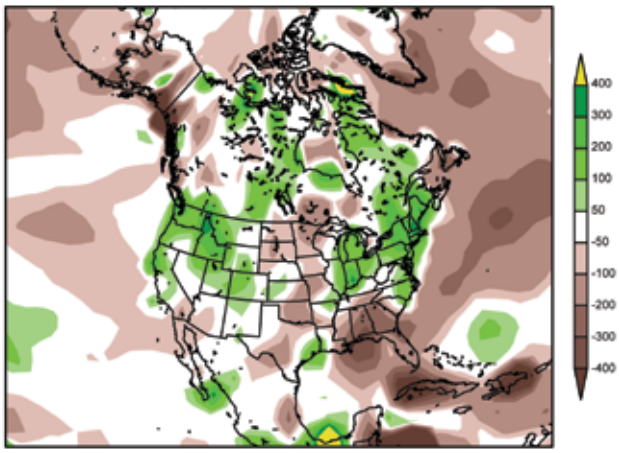

Fig. 6.10. North American 2006 annual precipitation anomalies (mm, 1979–2000 base) from CAMS-OPI.

59 years of nationwide records, 2.2% above the 1951–80 normal. This is in sharp contrast to 2005, which was the wettest on record, 13.4% above normal. Wetter areas of the country, those with more than 20% above normal, include the Arctic Islands, southwest British Columbia, central Saskatchewan, northern Manitoba and Quebec, and southern Ontario. Drier areas, those more than 20% below normal, include the western edge of the Northwest Territories, northern British Columbia, a few areas throughout Alberta, southern Manitoba, and northwest Ontario. One climate region, southern Ontario and Quebec, experienced its second wettest year (17.6% above normal); no climate region ranked among its 10 driest years. The southern prairies provinces experienced the driest value, –5.8% (22d driest).

(iii) Notable events

Vancouver, British Columbia, set a couple of records in January: the most rainfall for the month (283.6 mm, the normal is 154 mm) and the most number of days with rain (29). The warm season had the opposite effect, with a dearth of rain across much of Vancouver Island. The resort town of Tofino, on the west coast of the island and normally one of the wettest spots in Canada, received no significant rain between 14 July and 16 September. Consequently, the town's reservoir fell to record-low levels. November brought three notable storms to British Columbia's coast. The first, on 5 and 6 November, brought intense rains, at times 10–15 mm of rain an hour for 15 hours. A storm on the 15 November brought heavy rains to the Vancouver area, causing so much turbidity in the drinking water that an estimated two million people were advised to boil their tapwater before drinking. Then, on 25 November, a storm brought 40 cm of snow to Vancouver and Victoria, the amount they normally receive in a year. Three wind storms (greater than 100 km h^{-1}), all aimed at Vancouver Island and the lower mainland, were the hallmark of December.

Several tornadoes were reported across central Canada, resulting in one death and costing thousands in property damage. The death was the result of a tornado that hit Gull Lake, Manitoba, on a stormy day on 5 August. One storm system on 17 July generated a series of tornadoes and microbursts that affected areas from Lake Huron through Quebec, one of the longest storm tracks in Ontario's history. Another storm system hit Ontario in early August affecting cottage country, north of Toronto. Remarkably, nobody was killed in the 14 tornadoes that were

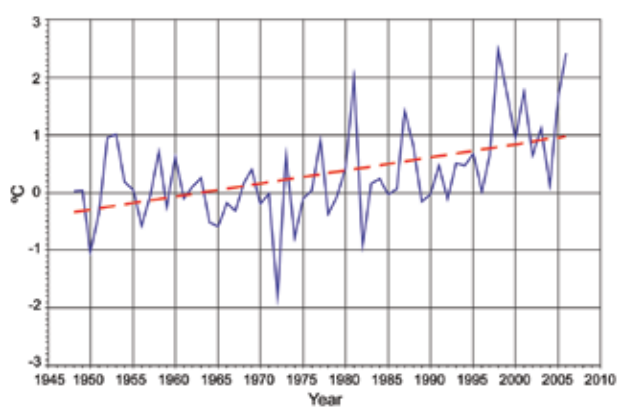

Fig. 6.11. Annual average air temperature anomalies (°C; blue; 1951–80 base) and the 1948–2006 linear trend showing a +1.3°C increase (red). [Source: Environment Canada.]

generated, two of which had winds speeds greater than 180 km h^{-1}. The Canadian Interagency Forest Fire Centre reported an active wildfire season. At the end of the fire season, 1 October, the center reported a total of 9,482 fires (27% more than normal), covering an area of 2,031,705 ha (4% more than normal) for all of Canada.

2) United States—R. R. Heim Jr., D. H. Levinson, N. B. Guttman, and A. M. Sanchez-Lugo

(i) Overview

Reliable monthly, seasonal, and annual weather records for the United States exist since 1895, enabling the climate of 2006 to be placed in a 112-year context. The nationally averaged temperature for 2006 was 12.72°C, ranking this year as the second warmest on record. The 2006 annual average temperature was only 0.04°C cooler than the record that occurred in 1998, and ~0.01°C warmer than 1934, making these three years nearly identical in rank (Fig. 6.12). These rankings are based on version 2 of the U.S. Historical Climatology Network. Note that ties are not indicated in figures; ties are labeled as duplicates of the more extreme ranking (e.g., a tie for ranking two and three is listed as two for both).

Nationally, annual precipitation was near the long-term mean, giving 2006 a rank of 55th driest year in the 112-year record. Considerable variability in precipitation occurred across the country and throughout the year. Florida had the driest March–December season on record in 2006, while Indiana ranked as the wettest on record for the same season. Significant drought expanded during the first half of the year, affecting ~52% of the country at its peak in July. The dry conditions were accompanied by a record wildfire season, with almost 10 million acres (~4 million ha) burned during 2006.

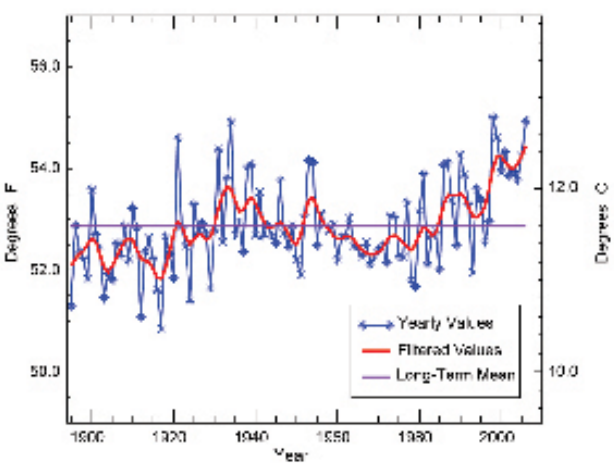

Fig. 6.12. Annual temperature (°F and °C) averaged across the contiguous United States from 1895 to 2006.

(ii) Temperature

For the contiguous United States, 2006 marked the ninth consecutive year with temperatures much warmer than the long-term average (Fig. 6.12). The past nine years have all been among the 25th warmest years on record, a streak that is unprecedented in the historical record. The long-term warming trend for annual temperatures is approximately 0.56°C (1.0°F) warmer than at the start of the twentieth century. National temperatures persisted at warm or record warm levels throughout 2006 with only two months (September and October) that were cool exceptions.

The 2005/06 winter season (December–February) temperatures were above average across most of the nation with near-average temperatures limited to parts of the Northwest and Southeast and no state ranking below average. The warmer-than-average winter season was due in part to record-warm temperatures that affected the nation in January. The nationally averaged temperature for January 2006 was 3.9°C, which is 1°C warmer than the previous January record set in 1953. All states within the contiguous United States were warmer than average during January, with 13 states, mostly located in the central and northern plains and Great Lakes, ranking as their record warmest.

Cold-air outbreaks affected the western states during March and the Southeast during May, but warm temperatures dominated the nation during the 2006 spring season (March–May). Much warmer-than-average temperatures affected most of the central states, with Texas and Oklahoma having the warmest spring on record. April ranked second warmest in the 1895–present record for the nation, with an average temperature of 13.4°C.

The summer (June–August) months were characterized by an intense and long-lasting heat wave that began in mid-July in the northern plains and upper Midwest, breaking records that stood since the Dust Bowl years in some locations. The heat spread across the plains and moved into the West before returning to the northern plains by late July, then spreading to the East Coast by the first week of August. More than 2,300 daily temperature records were broken in the United States during the last two weeks of July and several more during the first half of August; more than 50 records for the highest temperatures in any July were established. Many locations from the West

Coast to the central plains broke records for the most days above 32.2° (90°F) and 37.8°C (100°F). The month of July 2006 ranked as the second hottest month ever in the 112-year record, with a nationally averaged temperature of 25.1°C, only 0.24°C cooler than the record-hottest month—July 1936. Nationally averaged temperatures gave summer 2006 a rank of second warmest on record just behind 1934 (second warmest) and 1936 (warmest).

The persistent widespread warmth for much of the year resulted in the warmest January–August period on record. Colder weather during September and October brought a brief respite before unusual warmth returned to much of the country during November and December. December 2006 ranked fourth warmest on record.

For the year as a whole, New Jersey, Vermont, Oklahoma, and Texas were second warmest on record (Fig. 6.13a). Another 13 states had one of their top-five warmest years. All of the 48 contiguous states were either record warmest, warmer, or much warmer than average. No state ranked near or below average during 2006. This contrasts with the spatial pattern during the warmest and third warmest years, 1998 and 1934, when at least one state ranked colder than average for the year (Figs. 6.13b,c). The 2006 annual temperature for Alaska ranked near the 1918–2006 average, breaking a string of persistently warm years dating back to 2000. Winter temperatures in 2006 were above average for the seventh consecutive year. Both spring and summer were slightly cooler than average and fall was slightly warmer.

(iii) Precipitation and drought

Precipitation in the contiguous United States during 2006 was variable throughout much of the country, with periods of excessive rainfall, especially across the Northwest, Great Lakes, and Northeast, and persistent and developing drought in other areas. Winter storms in the Northwest contributed to the ranking of 10th wettest winter for the region. The Southwest had its second driest winter, with Arizona and New Mexico having their driest winters on record. Precipitation averaged across the nation was below average during spring. Regionally, the Southeast had the third driest spring, whereas the West ranked as the sixth wettest. The Northeast had its wettest summer, exceeding the previous record by more than 25.4 mm (1 in.), while the region consisting of the Northern Great Plains and northern Rockies states had its ninth driest summer. Three states (New Hampshire, New York, and Rhode Island) had the wettest summer on record. Fall was generally wet across the contiguous United States, resulting in a rank of 15th wettest for the nation. Regionally, the Northwest and Northeast ranked as having the 10th and 4th wettest autumn periods, respectively.

Five of the first seven months of the year were drier than average for the contiguous United States as a whole. Combined with unusually warm temperatures, this exacerbated drought across much of the country. By late July, half of the contiguous

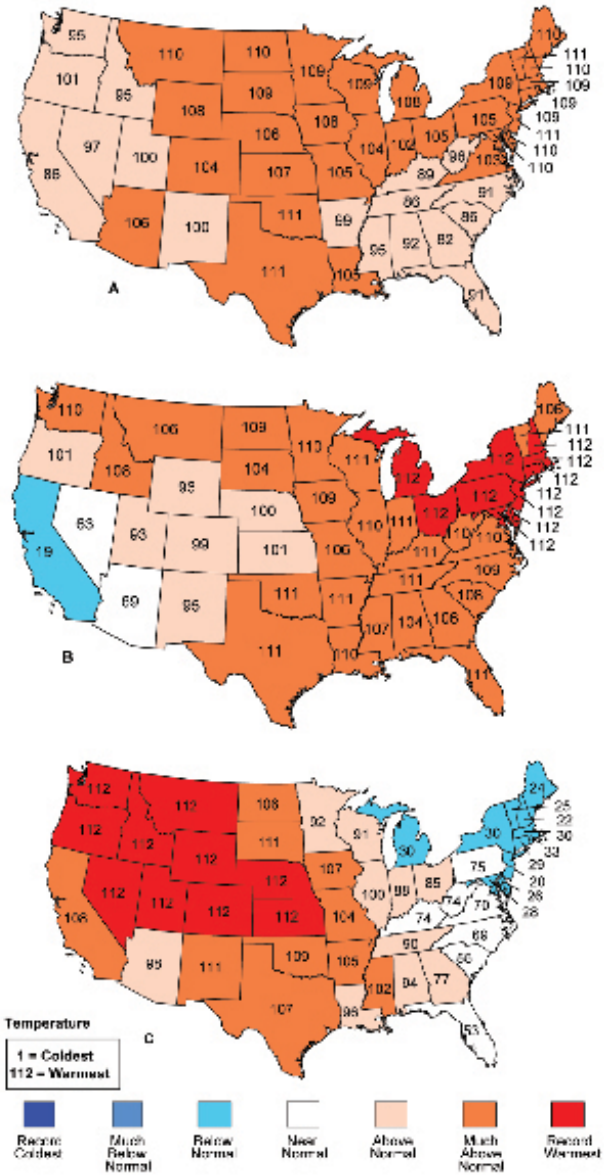

Fig. 6.13. Statewide rankings (as of 2006) of annual temperature as measured across the contiguous United States for (a) 2006, (b) 1998, and (c) 1934. A rank of 112 (1) in the record represents the warmest (coldest) year in the 1895–2006 period. Ties are included as duplicates of the more extreme ranking. [Source: NOAA/NCDC.]

United States was in moderate to exceptional drought. Annual precipitation ranks ranged from third driest in Florida and fifth driest in Wyoming and Georgia, to second wettest in New Hampshire and third wettest in Indiana. The Northeast had another wet year, ranking sixth wettest in 2006 and marking the fifth consecutive year with above-average precipitation. In fact, the top two wettest annual periods in New Hampshire occurred during the past two years. Nationally, annual precipitation was near the long-term mean, ranking as the 55th driest year on record.

The year began drier than average across a broad swath of the country from the Southwest to the Great Plains, across much of the Gulf Coast, and into the coastal Southeast. Above-average precipitation continued to erode the drought areas in the Pacific Northwest. This pattern continued throughout the spring and into the summer (Fig. 6.14). By fall, drought was concentrated in the plains, especially in Texas and Oklahoma. By the end of the year, drought subsided in much of the Southeast, but was prominent across parts of the plains.

Several short-lived dry episodes occurred in other regions throughout the year, notably in the mid-Atlantic in February and March, the Northeast coast in March, the Pacific Northwest in July and August, and Florida for much of the year. The percent area of the contiguous United States experiencing moderate to extreme drought (as defined by the Palmer Drought Index) grew steadily from 20% in January, to a peak of about 52% by July, and then declined during the second half of the year. Impacts from the 2006 droughts were felt especially hard by the agricultural and hydrological communities. The South Platte River was nearly dry during the summer, low water levels in the Mississippi and Missouri Rivers forced an early end to barge transportation, several municipalities imposed water use restrictions, livestock was prematurely sold, and crops died before harvest. In some areas, such as in South Dakota and Nebraska, recovery of grazing lands from drought is not expected for at least two years.

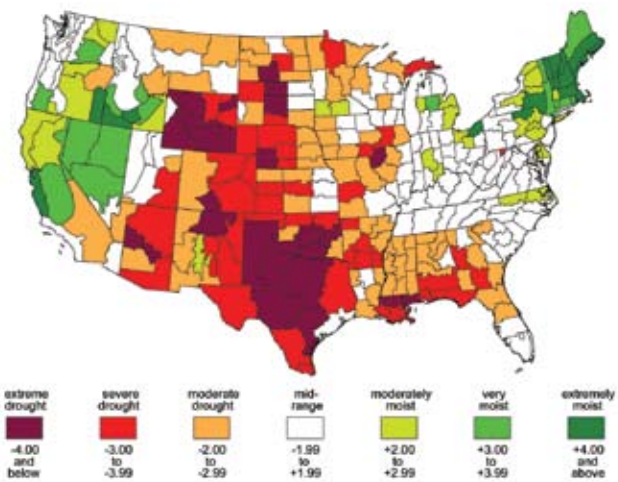

Fig. 6.14. Palmer Hydrological Drought Index showing the spatial pattern of drought across the contiguous United States during July 2006. [Source: NOAA/NCDC.]

(iv) Snowpack

The 2005/06 snow season was generally above average across parts of the Northwest and below average across the Southwest. The snow cover extent was below average for the North American continent as a whole during the winter season, in which January 2006 had the second lowest snow cover extent behind 1981, as well as during the spring season. This is consistent with a trend toward reduced spring snow cover for North America since 1986. By the end of the spring season, snowpack was above average across the western mountains from the Sierra Nevada in California to the Washington Cascades, and into the interior Northwest.

Notable snow storms in 2006 include a blizzard during the month of February that affected areas of the Mid-Atlantic and the Northeast on 11–12 February. This storm produced 68.3 cm (26.9 in.) of snow in New York City's Central Park. This amount broke the all-time storm total record of 67.1 cm (26.4 in.) set during the 26–27 December 1947 storm. The NESIS classified the February blizzard as a category 3 (major) storm and ranked it as the 20th most intense on record for the Northeast. In Hartford, Connecticut, a snowfall total of 55.6 cm (21.9 in.) broke the old storm total record of 53.3 cm (21 in.), set in 1983. Many locations in the region reported 25–51 cm (10–20 in.) during this event.

An active Pacific storm track during the winter and spring brought a steady supply of snow to the West, Northwest, and Intermountain West. On the other hand, snowfall across Arizona and New Mexico was exceptionally low throughout the season, with most basins reporting less than 40% of normal snowpack at the end of spring.

The 2006/07 snow season started with above-average snowfall across parts of the West. Snowfall accumulations of up to 60 cm (2 ft) fell across the Cascades in late November. During December 2006, two major winter snow storms impacted Colorado and parts of the High Plains. Denver, Colorado, had its third snowiest December on record and endured a major blizzard, which brought the city to a standstill

during the holiday travel season. Snowfall in excess of 90 cm (3 ft) fell across portions of the Colorado Front Range and western High Plains during these two events.

(v) Wildfires

Continuing a pattern of increased large fire activity that extends back to the early 1990s, wildland fires reached record levels in 2006. According to the NIFC, preliminary estimates of the area burned exceeded 9.8 million acres (~4 million ha) across the United States this past year. In contrast to the total acreage burned, the annual number of wildfires has decreased steadily since the 1980s; over 96,000 fires were reported in 2006, which was the sixth consecutive year that the annual number of fires for the entire United States has been below 100,000. As discussed by Westerling et al. (2006), there has been an increasing trend of larger wildfires across the West, where the inverse relationship between increasing area burned and decreasing number of fires has been the most pronounced.

There were several notable aspects to the record fire season in 2006, in terms of its timing and severity. Wildfires that initially began across the southern plains in December 2005 persisted into early 2006. Below-normal precipitation and extreme drought conditions aided in the development of numerous wildfires across Oklahoma, Texas, and Arkansas, with over 1.5 million acres (~600,000 ha) burned over the first three months of the year in the southern area (which encompasses 13 states, Puerto Rico, the Virgin Islands, and the District of Columbia). During the spring, fire activity spread to the Southwest, with the most severe activity concentrated in New Mexico and southern California. By summer, wildfires had spread into the Great Basin and Pacific Northwest, with large fires affecting most of the West by the end of July. Large fire activity spread northward, because the Pacific Northwest was the focal area in August and early September, while during the fall, activity shifted again into southern California.

(vi) Severe extratropical storms

Several severe extratropical cyclones affected the United States in 2006. The first of these occurred early in the year on 18 January, when a powerful winter storm brought heavy rainfall, strong winds, and heavy snowfall to sections of the East Coast. During the spring peak in severe weather, several tornado outbreaks occurred in the southern plains, as well as the Tennessee and Ohio valleys, which produced over 500 tornadoes and nearly 50 fatalities during March and April combined. Northwestern Tennessee was the hardest hit region, with 23 fatalities attributed to the storms. According to preliminary statistics compiled by NOAA's Storm Prediction Center, there were 1333 tornadoes reported across the United States in 2006, with April having the most of any month (324). The most severe day of the year was 12 March when 142 tornadoes were reported.

Two large extratropical storms of note occurred toward the end of 2006. On 21–22 November, a strong extratropical cyclone developed off the southeastern coast of the United States, producing a variety of severe weather events in the Southeast and Mid-Atlantic. Heavy rainfall and strong winds were reported along the coastline from South Carolina northward through Virginia. Winds gusting over 115 km h^{-1} (70 mph) were reported along the coast of North Carolina. On 13–15 December, a powerful storm system came ashore along the Pacific Northwest coast and generated strong winds, heavy rainfall, and high-elevation snows. Wind gusts reaching hurricane force caused power outages across Washington and Oregon.

3) Mexico—V. Davydova Belitskaya and A. Douglas

Mexico was on average 5% wetter than normal in 2006, with much warmer than normal temperatures. Mexico's SMN reported a national precipitation average of 808 mm, compared with an historical average of 771 mm (1941–2000). The nationwide annual mean temperature was 21.9°C, which was a 1.2°C above the long-term climate average. However, it should be noted that most of the stations used to create the nationwide temperature values are in large urban centers. In light of inherent heat island biases in the underlying data, which are currently unaccounted for, care should be taken in interpreting the 1.2°C climate anomaly.

The rainfall distribution was not homogeneous throughout the year or across large sections of the country. The year started abnormally dry but it quickly recovered with a good rainy season from May to October (total rain or warm-season precipitation was 111% of normal according to the SMN; see Fig. 6.15). The summer of 2006 was typified by widespread and consistent monsoon rainfall through much of the country; this helped to raise reservoir levels throughout the western states following a long series of dry winters in that region.

Some states reported major rainfall deficits for the year. These include Baja California (46% below the long-term mean), San Luis Potosí (25% below), México and Yucatan (19% below), Oaxaca and Sonora (16% below), Hidalgo (15% below), Zacatecas

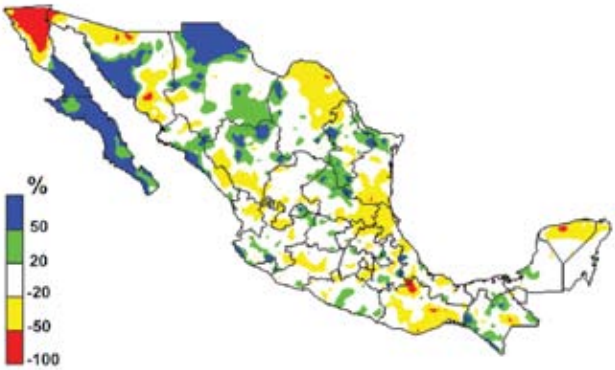

Fig. 6.15. Precipitation anomalies (%) during the May–October 2006 rainy season in Mexico.

and Tamaulipas (12% below), Quintana Roo (10% below), and Sinaloa (7% below). The deficits in the northwest were associated with a poor winter rainy season in early 2006 and again in late 2006. The development of El Niño conditions during the later half of the year was associated with four east Pacific tropical storms that recurved toward the west coast of Mexico: John, Lane, Norman, and Paul. In contrast, there were no landfalling tropical storms on the east coast of Mexico; this helped to contribute to the observed dryness in the Yucatan Peninsula and northeast Mexico.

Despite the very warm annual mean temperature; a notable cold outbreak occurred in northern Mexico on 17 January when Temosachic and La Rosilla recorded –15°C, Yecora recorded –10°C, Pabillon recorded –7°C, and Saltillo recorded –4.5°C. An exceptionally early winter cold outbreak occurred in the northwest on 1 December, with La Rosilla falling to –13.5°C and Temosachic to –12°C. One of the most significant and highly unusual meteorological events occurred during the last week of the year in the states of Chihuahua and Durango when very heavy snows covered the western section of the these two states, with mountainous areas exceeding well over 10 in. of snow.

d. Central America and the Caribbean—P. Ramírez and J. Peréz Fernández

1) Precipitation

Most of the Central American isthmus and the Caribbean experienced drier-than-normal conditions in 2006 (Fig. 6.16). Precipitation deficits were severe and more persistent over what is known as the "dry corridor" of Central America (western Guatemala, central Honduras, northern and central Nicaragua, and western El Salvador). August had the highest precipitation deficits compared to the 1971–2000 period. Precipitation deficits continued during September and October along the dry corridor. In parts of Nicaragua and Honduras, deficits between 35% and 55% of the long-term mean were observed in September and October. October is when most tropical cyclones form close to Central America, generating very intense rains or "temporales" on the Pacific side of the isthmus. The temporales were lacking in autumn 2006, because El Niño conditions were observed in the tropical Pacific. In November, the Caribbean side of Central America was affected by a cold front that brought strong rains to the northern Honduras coast and central Panama. Late-year rains, associated with the divergent phase of the MJO, were observed on the Pacific side of Central America through the middle of December.

2) Temperature

Annual mean surface temperature in 2006 was above normal across much of Central America and parts of the Caribbean (Fig. 6.17). Positive anomalies of between 0.3° and 0.4°C were found over Central America (south and west of Honduras and El Salvador, Nicaragua, and northern Costa Rica), and were near normal across Panama. Temperatures that were near normal predominated the first two months of the year. In March, resulting from a late intrusion of cold fronts into the region, below-normal monthly means were observed in Belize, western Guatemala and Honduras, and western Panama. At the same time, positive anomalies were registered in Costa Rica and Nicaragua. Positive anomalies dominated along

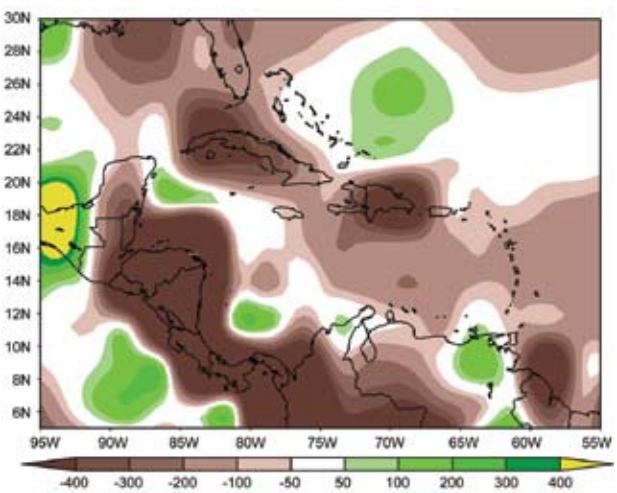

Fig. 6.16. Central American and Caribbean 2006 annual precipitation anomalies (mm, 1979–2000 base) from CAMS-OPI.

the whole region from May to October. The warmest conditions, relative to climatology, were observed in July and August, when monthly departures from the 1971–2000 mean exceeded 0.5°C. In November, mean temperatures in northern Central America (northern Guatemala and Belize) showed negative anomalies. In the southern extreme of the Central American isthmus (eastern Panama), temperatures remained above normal. The whole region showed positive anomalies once again in December.

3) Notable events

In 2006, the reduced hurricane activity in the Caribbean (consistent with the development of a weak El Niño event) spared Central America from heavy rainy events, creating a stark contrast between 2006 and 2005, when tropical cyclones had a significant impact on the region. Also consistent with El Niño, Central America experienced drier-than-normal conditions in the latter half of 2006. Cold surges in November impacted the region with low temperatures in the north and stronger-than-normal winds and rainfall in southern Costa Rica and Panama. The surges caused significant damage to vegetable crops in the Guatemala Plateau. Along with high humidity values, heavy flooding events produced floods in the Caribbean plains of Honduras and central Panama, where more than 450 mm of rain fell in some parts between 20 and 28 November.

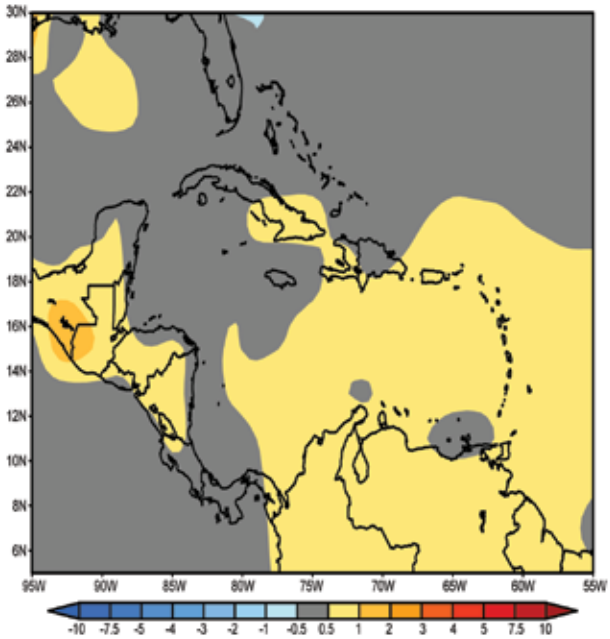

Fig. 6.17. Central American and Caribbean 2006 annual temperature anomalies (°C, 1971–2000 base) from CAMS-OPI.

COUNTRY SPOTLIGHT: CUBA—R. Peréz Suárez, C. Fonseca Rivera, B. Lapinel Pedroso, V. Cutié Cansino, A. M. Carrión Romero, M. Hernández Souza, and D. Boudet Roco

The Cuban climate in 2006 was affected by the weak El Niño, primarily from September through December. Precipitation was lower than normal in September and October. In November and December, precipitation was above normal as cold fronts reached the Caribbean, and the subtropical jet was southeast of its usual position (consistent with El Niño). December was a particularly warm month across Cuba.

The year 2006 as a whole was very warm (11th warmest since 1951), with an average temperature of 25.85°C, 0.36°C above normal (Fig. 6.18). January and December contributed most to the warm anomaly. January, the coldest month, brought positive anomalies of 0.5°–1°C across Cuba, whereas December was the second warmest since 1951 (just behind 1986). Many Cuban stations broke maximum or minimum temperature records in 2006, especially during a cold outbreak in late November.

Rainfall deficits affected parts of western and central Cuba. Eastern parts received abundant rainfall, including Holguín y Guantánamo (comparing against the 1971–90 normal). Tropical cyclones Alberto and Ernesto both impacted Cuba. In June, Alberto brought intense rains to western Cuba, especially in Pinar del Río and Isla de la Juventud.In August, Ernesto brought torrential rains to central and eastern Cuba. Despite these two storms, the 2006 hurricane season was relatively quiet for Cuba, considering the activity witnessed this decade.

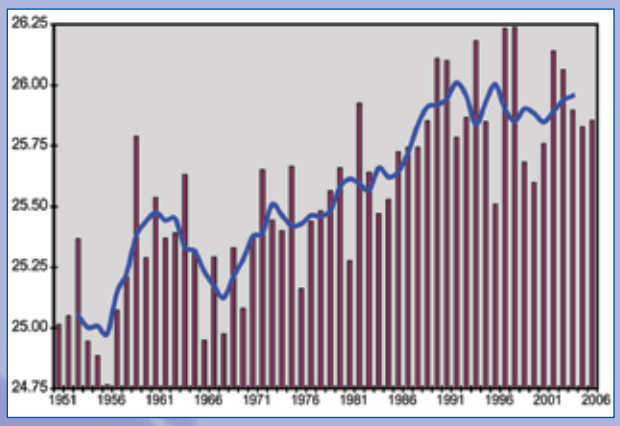

Fig. 6.18. Annual average temperatures (°C) over Cuba from 1951 to 2006.

e. *South America*

1) Overview—M. Rusticucci and J. L. Camacho

The overall weather in South America in 2006 was very dry or wet in parts (Fig. 6.19), but largely warmer-than-normal (Fig. 6.20). La Niña conditions prevailed in the central equatorial Pacific for a few months at the start of the year. A weak-to-moderate El Niño event developed by the middle of the year; it reached its maximum strength by late November. Modulation by the MJO also played a role. Some extreme rainfall events occurred in Colombia and Ecuador. In July–August, ENSO shifted to the warm phase. In the second part of the year, some classical teleconnections were active, especially in central or Atlantic areas. Most notably, there were no reports of hurricane activity in the north. However, the teleconnections over the Pacific side were less clear and the ITCZ in the eastern Pacific was not as intense as expected.

For temperature, the most important feature was the overall positive anomaly. Consistent with the overall warming pattern since 1950 (Fig. 6.21), 2005 and 2006 were warmer than average, though not reaching the peak of 1998. Some areas of Brazil experienced record-breaking temperatures in austral summer, for example, the 44.6°C record for Bom Jesus on 31 January. A belt from northern Argentina, Paraguay, Uruguay, and southern Brazil showed a marked warm anomaly in July. In contrast, fall (April–May) was cold in the tropical Andes and in southern areas due to marked cold-air advection. Extreme temperature variability on weekly or monthly time periods was noteworthy in Brazil.

Rainfall anomalies were highly variable across the region. The Andean territory of Colombia and Venezuela was in general above average. Neighboring areas of Orinoco and Amazonian basins were below average. There was yet another year of drought, adding to the long-term event that southern Brazil, Uruguay, and parts of Argentina have been enduring. Much of southern Peru, a relatively arid zone, had rainfall clearly above normal. South-central Chile (near 40°S), the rainiest area in the country, received more rain than normal, as did Patagonia. A combination of extreme events and passage of fronts more frequent than normal in the second half of the year could explain this fact.

2) Northern South America and the southern Caribbean—J. D. Pabón, G. Hurtado, and M. Henriquez

During the first half of 2006, the climate over northern South America was influenced by La Niña conditions. Precipitation was above normal over Caribbean and Andean sectors of Colombian territory and western Venezuela. In May–June, these conditions were accentuated by the effects of a strong convective phase of the MJO. Consequently, heavy rainfall events produced landslides, flash floods in mountain regions, and lowland floods, killing over 100 and affecting over 100,000.

Monthly mean air temperature during the first six months in the region was between near normal and slightly below normal, with the exception of February when isolated regions recorded slight positive anom-

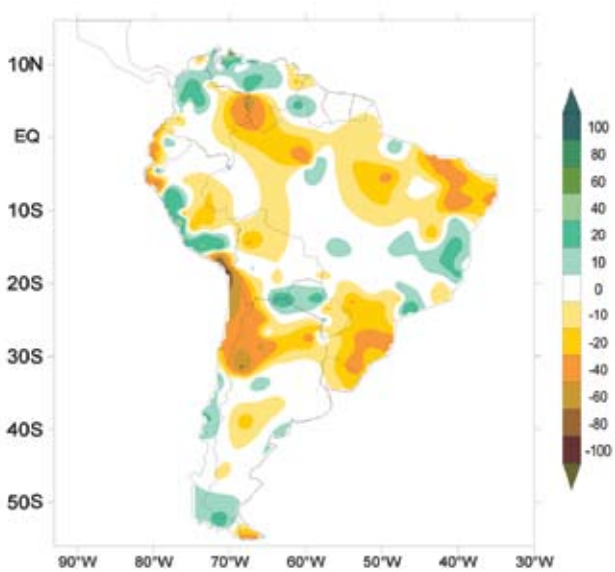

Fig. 6.19. South American 2006 annual precipitation anomalies (mm, 1979–2000 base) from CAMS-OPI.

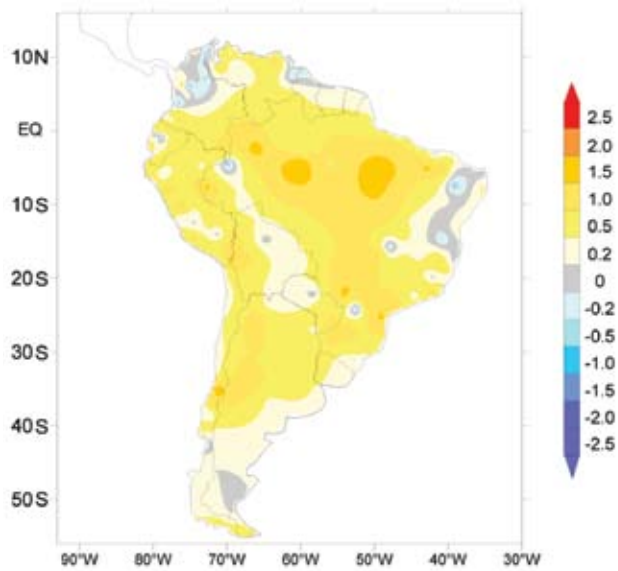

Fig. 6.20. South American 2006 annual temperature anomalies (°C, 1971–2000 base) from CAMS-OPI.

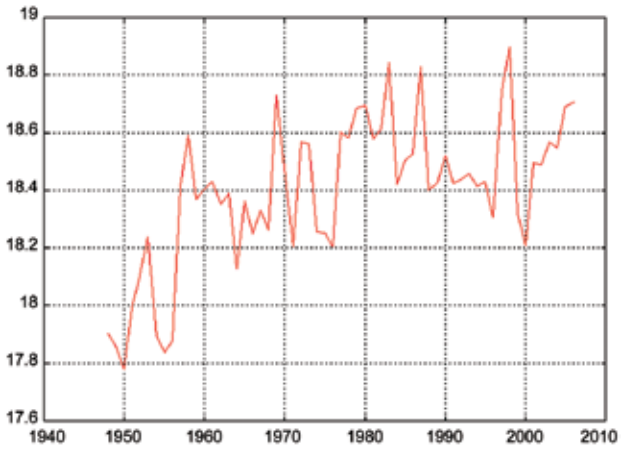

Fig. 6.21. Time series of annually averaged air temperature (°C), spatially averaged from 15°N to 55°S and 30° to 90°W, for the 1948–2006 period. [Source: NCEP–NCAR reanalysis at www.cdc.noaa.gov/cgi-bin/Composites/.]

alies. Negative anomalies of monthly precipitation dominated over the region from July to October. The rainfall deficit was strong in September–October thanks in part to a subsidence phase of the MJO (Fig. 6.22). A very strong convective phase of the MJO was observed in November over northern South America; this phase reactivated rainfall over the region and above-normal precipitation was reported for November–December.

In the period from July to September, monthly mean air temperatures were near to below normal. In October, some sectors recorded slight positive air temperature anomalies, and during November–December, consistent with El Niño, positive anomalies dominated the region. As in the tropical Atlantic, the tropical cyclone season in the Caribbean Sea was not active. Only some tropical waves (easterly waves) observed over the Caribbean Sea influenced the weather of the Caribbean sector of this region.

3) Tropical Andean region—E. Jaimes and R. Martínez

During January and February, the South Pacific anticyclone was between normal to slightly more intense. The frequency of inverted troughs brought warmer conditions to the Peruvian coast. The ITCZ and the ET were located slightly north of their normal position. However, the Bolivian high was located to the west of its normal position, favoring significant rains over the central and southern mountain regions in Peru and affecting the mountain region of Bolivia with some scattered rains. Conversely, the periodic formation of the Atlantic convergence zone contributed frequent rains over the Amazonian region in Brazil, Bolivia, and Peru. In March, the formation of a second band of the ITCZ in the eastern Pacific Ocean was observed, close to 5°S with moderate activity. The ET formed near 8°S with convective activity in the Amazonian region of Brazil, causing rains and storms with an intensity ranging between moderate and strong. Conversely, some migratory highs caused instability in the atmosphere, forming convective complexes in the jungles and highlands of Bolivia.

For the April–May period, the South Pacific anticyclone started to show some intensification, typical of the season; however, a second band of the ITCZ persisted, though smaller than in March, favoring rains along the Peruvian coast. In some days in April, migratory highs were generated (up to 1030 hPa) that favored the presence of strong winds from the south, affecting northern Argentina, Paraguay, Bolivia, and south-central Peru with cold and dry air. This led to significantly lower temperatures in the southern jungles of Peru. Early meteorological frosts occurred in many parts of the southern mountainous region in Peru and in the highlands of Bolivia.

The South Pacific anticyclone and ITCZ moved to the north during austral winter, as expected. In July, a thermal orographic low was observed at 1005 hPa and contributed to the convergence of humidity and

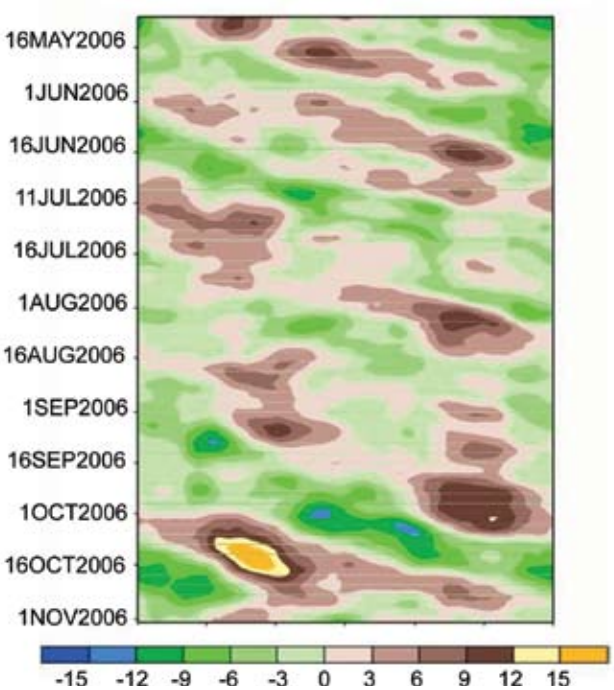

Fig. 6.22. Hovmöller diagram, averaged from 5°S to 5°N, of 200-hPa velocity potential anomalies. [Source: www.cpc.ncep.noaa.gov/products/.]

to the increase of air temperatures in Paraguay, the southern jungles of Bolivia, and the north and central parts of Argentina. In August and September, the migratory highs systems in the continent were very frequent (though not very intense), keeping the skies clear. Frosts occurred in many areas located near 2500 m above sea level in the Amazonian regions of Bolivia, Peru, and Brazil. In November, there were some circulation patterns considered to be characteristics of (an early) austral summer, such as the behavior of the Bolivian high. This caused heavy precipitation over Huanuco, San Martin, and Ucayali; it later affected Bolivia with strong winds from the north.

4) Tropical South America, east of the Andes—J. Marengo

In general, the most important feature of summer rainfall for 2006 was the occurrence of rainfall extremes that produced floods and avalanches, claiming lives and resulting in huge economic losses. During the summer of 2006 (December 2005—March 2006), and following a drought situation that affected southwestern Amazonia during most of 2005 (Marengo et al. 2007, manuscript submitted to *J. Climate*), the Brazilian state of Acre experienced abundant rainfall. Below-normal precipitation was observed in southeastern South America, featuring a drought situation in southern Brazil and neighboring Uruguay, which has lasted at least 3 years. Changes in Southern Hemisphere circulation may be the cause of this extended drought. Meanwhile, most of northern South America and Bolivia saw above-average amounts of rainfall. In January, Bolivia was affected by destructive flooding and landslides.

Intense rainfall during the end of 2005 and beginning of 2006 caused flooding along rivers and coastal areas of Guyana, including the capital, Georgetown. Thousands of acres of farmland in Barima Waini and Mahaica Berbice were lost due to flooding. In the state of Bahia in the southern section of northeast Brazil, drought affected the agricultural production with losses of about 30% in corn and 29% in bean production. By the end of summer and the beginning of the fall season (March–May 2006), abnormally heavy rainfall of about 200 mm above normal in the Brazilian state of Para caused flooding along the Tocantins, Xingu, and Tapajos Rivers, all of which are Amazon River tributaries. Meanwhile, heavy rainfall triggered new flooding and landslides in Colombia, particularly along the Pacific coast and in central sections of the country during January and February, with values between 100 and 150 mm month^{-1} above normal.

Consistent with the weakening of the cold episode in the Pacific in 2006, northeastern Brazil, northern Argentina, and southern Peru experienced above-average rainfall, while Uruguay, southeastern Brazil, and much of Colombia had a deficit of rainfall during April. The rainy season in northeast Brazil that extends from February to May was near normal. In July–September 2006, dry anomalies characterized northern and southeastern South America, from northern Colombia to Venezuela, with deficits of about 200 mm month^{-1} below normal. September and October featured abundant rainfall (about 200 mm month^{-1} above normal) from the transition region between Amazonia and northeast Brazil, extending up to southeastern Brazil. The latter region (especially the region off the coast) experienced above-normal rainfall until December 2006, due to the penetration of frontal systems coming from the south.

Most of tropical South America, east of the Andes experienced a warm 2006, with anomalies between 2° and 3°C warmer than normal, especially during summer between the Andes and eastern Amazonia. Temperature records were broken in the austral summer in Brazil. Record highs above 41°C were also detected in other cities in southern Brazil in January 2006. Associated with the extended drought, these were among the highest temperatures during the last 40 years. In May, in a notable departure from recent trends, many Southern Hemisphere land areas saw temperatures well below average, including much of western Brazil, and southward to Uruguay, Paraguay, and northeastern Argentina. During September, extreme cold weather affected southern Brazil. During the austral winter season, air temperatures in tropical South America east of the Andes were very high, sometimes about 3°C warmer than normal. The city of São Paulo reached a maximum of 30.2°C on 24 July (a record for the last 63 years), accentuating the notion that the Brazilian winter of 2006 was highly irregular, being warmer than normal in most of Brazil even though extreme cold days occurred.

5) Southern South America—P. Aceituno, M. Bidegain, J. Quintana, and M. Rusticucci

Temperature anomalies were positive in 2006 over most the region. Anomalies between 0.5° and 1.5°C were observed in northern Argentina, northern Chile, Paraguay, and northwest Uruguay. The beginning of 2006 was anomalously warm in northwest Argentina and Chile. In southern Uruguay and the province of Buenos Aires, mean temperature was slightly below normal. Autumn in southern South America was

characterized by below-normal temperatures along Uruguay and eastern Argentina (+0.2° to –1.0°C), particularly during May, when the negative anomalies extended into Paraguay, southern Brazil, Bolivia, and the southern portion of the Amazon basin. The winter season was warm over the entire region with temperatures from +1.0° to +2.0°C over the climatological mean. June and July were exceptionally warm in Paraguay, northern Argentina, Uruguay, and southeast Brazil. In July, mean temperature anomalies exceeding +4.0°C were observed over Paraguay and the surrounding regions, while the area with anomalies above +2.0°C included most of the continental territories between 6° and 38°S. The warm spell ended abruptly by the end of the month due to a powerful cold-air incursion than also affected southern and western Brazil, Bolivia, Peru, and southern Colombia. In Uruguay, the daily mean temperature dropped around 10°C between 26 and 27 July, while frost was observed in central Argentina and daily minimum temperatures below –10°C occurred in the southern part of the country (Patagonia).

The spring season showed positive anomalies of the order of +0.5° to +1.0°C. Significant weather events occurred in Argentina during July. During the first half of the month, a high pressure system located on the eastern side of the continent favored the advection of warm and moist air from the Amazon basin. An extreme Zonda event occurred between 11 and 12 July, producing significant property damage. At the same time, a powerful winter storm hit central Chile and caused significant flooding. On 26 July, a warm and wet air mass affected the central and northern portion of the country, provoking rain showers and intense thunderstorms.

Across northeast Uruguay and southern Brazil, the moderate-to-exceptional drought that persisted during 2006 contributed to a record low in the Uruguay River level. Nevertheless, on 23 March, the most intense rainfall episode in the last 50 years (232 mm in 24 h) affected southeast Uruguay and the adjacent territory in southern Brazil. During another intense rainfall episode that affected the Uruguayan coast of the La Plata River on 17 December, 200 mm were measured at Nueva Palmira during a 24-h period. In contrast, a seasonal rainfall deficit of about 40% characterized the eastern Uruguayan territory of the Laguna Merin basin (along the border with Brazil).

The rainfall regime along the extratropical west coast of South America is determined by the frequency and intensity of cold fronts moving eastward in the southeast Pacific. The year 2006 ended with a rainfall surplus between 10% and 20% at most of the stations south of 30°S. However, the rainy season started late in central Chile (30°–35°S), with a rainfall deficit at the end of May that was nearly –70%. The anomalously intense frontal activity in June produced a quick recovery from the deficit. Very wet conditions continued during July along the west coast of the continent, southward from 30°S. A powerful extratropical winter storm hit the region from 9 to 12 July, producing landslides, flooding, and damage associated with strong winds. The 107 mm of rainfall measured at Concepción (37°S) on 10 July was the second highest daily rainfall reported at this station since 1950. The region of Bio-Bio in central Chile (around 37°S) suffered the greatest damage and was declared a disaster zone. The passage of this frontal system, with associated strong westerlies in the middle troposphere, was the origin of a severe episode of Zonda winds along the eastern side of the Andes on 11 July. Although August was relatively dry in central Chile (30°–35°S), an extraordinary rainfall episode occurred along the extremely arid region of northern Chile during the night of 29 August, associated with the arrival of an extratropical cyclonic disturbance. Precipitation (7.7 mm at Antofagasta, 23°S) and strong winds produced considerable damage in urban areas of this region where it very seldom rains.

6) Notable events

(i) Drought in southern Brazil—J. Marengo

Southern Brazil exhibited a regular pattern of precipitation, with maxima in austral spring and autumn. An analysis of rainfall since January 2003 to June 2006 shows that precipitation was below the climatological mean during most of the period (especially during the peak season) with above-normal rainfall outside the rainy season. During 2004 and the period between December 2005 and June 2006, rainfall has been below normal. This drought especially impacted the hydroelectric sector, with precipitation below 60% of the long-term mean over the basins of the Uruguay, Jacui, and Iguaçu Rivers. During the 2006 winter, the reservoir levels along these basins reached values lower than 20% of their averages. The drought produced severe impacts in the state of Rio Grande do Sul in southern Brazil during the first six months of 2006, with losses of 11% and 48% reported for the soybean and wheat harvest, respectively. Rainfall deficits were also observed in neighboring northern Uruguay during this time of year. Rainfall in Rivera/Santana do Livramento, near the Uruguay/Brazil border, was about 60% of the normal. Discharge of the Uruguay (Fig. 6.23) and

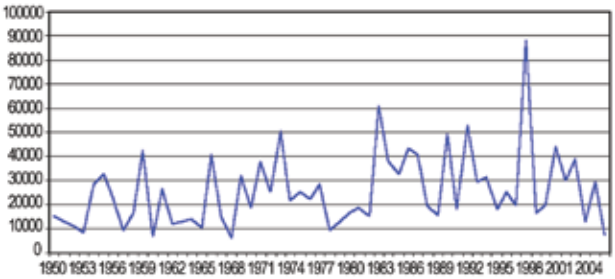

Fig. 6.23. Seasonal January–June discharge ($m^3 s^{-1}$) of the Uruguay River at Salto Grande during 1950–2006.

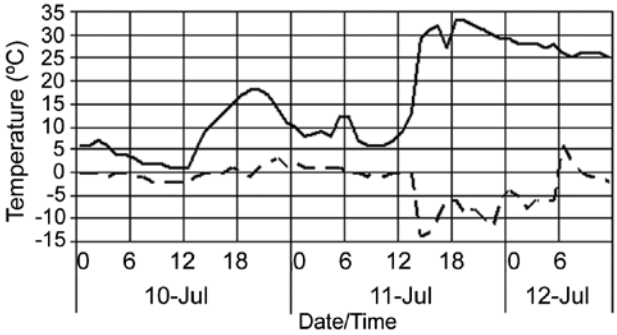

Fig. 6.24. Hourly evolution of surface temperature (°C) and dewpoint temperature (°C) in San Juan, Argentina.

Negro Rivers reached their lowest values since 1968, producing shortages in hydroelectric power in the whole country.

The SPI, as defined by McKee et al. (1993, 1995), quantifies the drought in southern Brazil. The SPI accounts for the various time scales at play during drought and subsequent rains. For the last four years, the SPI values were lower than the moderate (–1.0) to very dry (–1.5) threshold. The drought situation affecting southern Brazil is not just the consequence of the rainfall deficit in 2006, but is due to a rainfall deficit that has accumulated during the last three years.

The causes of this extended drought have been linked to variability in the regional circulation. Cold fronts represent the main rainfall-producing mechanisms in southern Brazil. An assessment of the number of cold fronts during January 2003–June 2006 affecting the region shows that this number was below normal. This behavior is consistent with an increase in the frequency of blocking systems in southern South America and a reduction in wavenumber in the higher latitudes of the Southern Hemisphere.

(ii) The Zonda event in Argentina—F. Norte, G. Ulke, S. Simonelli, and M. Viale

The Zonda is a strong, warm, and very dry wind associated with adiabatic compression upon descending the eastern slopes of the Andes, preferentially in winter and spring. It is the Argentine version of katabatic winds, which are also called mistral, chinook, Santa Ana, and foehn winds in different parts of the world. Although this phenomenon occurs across the entire length of the extratropical Andes, it is most frequently detected near the cities of Mendoza (33°S) and San Juan (31.5°S), which are the most populated cities in western Argentina (1.5 million inhabitants).

Four categories define the strength of the Zonda. The top two categories, "severe" (Z3) and "extremely severe" (Z4), respectively, account for less than 8% of Zonda events (Norte 1988). The event of 11 July reached categories Z3 and Z4 in the surrounding area of Mendoza and San Juan, where wind speeds reached over 120 km h^{-1} during a 2–3-hour period without interruption.

The synoptic surface and upper-air conditions were the typical ones associated with a severe Zonda wind occurrence: 1) a surface cold front approaching the central coast of Chile driven by a 500-hPa-level trough, 2) a deep low pressure surface system approximately over 55°S and 65°W, and 3) a strong upper-level jet stream. The main feature of the event is the sharp polar air advection from the south and an intense meridional 500–1000-hPa thickness gradient. The occurrence of the Zonda episode was characterized by a marked increase in temperature and a decrease in humidity. Thus, in Mendoza, the temperature reached 28.2°C while the dewpoint dropped to –6°C. At San Juan, the air temperature rose to 33.0°C, and the dewpoint fell to –15.0°C (Fig. 6.24). The Zonda caused severe impacts in the region, including fires, power outages, fallen trees, and destroyed buildings.

f. Asia

1) West and central Asia—O. Bulygina, N. N. Korshunova, and V. N. Razuvaev

The year 2006 in Russia showed near-normal rainfall (Fig. 6.25), while much of the country was quite warm (Fig. 6.26). The anomaly of the mean annual air temperature averaged over the Russian territory was 0.5°C. In early 2006, most of the Russian territory experienced severe frosts. Record-breaking low mean monthly temperatures were recorded in western Siberia. In both the Yamalo-Nenets Autonomous Area and the Khanty-Mansisk Autonomous

Area, the minimum air temperature dropped as low as –58°C. Six meteorological stations in the Tomsk region recorded temperatures that were 0.1°–0.4°C below the absolute minimum. Daily anomalies exceeded –25°C.

In the Kemerovo region, thermometers dropped to –53°C. In the second and third 10-day periods, record-breaking anomalies were recorded in the Tomsk and Kemerovo regions and in the Krasnoyarsk Territory. This winter, the Siberian anticyclone moved far to the west of its usual position over Yakutia. The anticyclone center was over the southern part of the Krasnoyarsk Territory. Therefore, severe frosts persisted there for a long time. At the station of Bor, frosts below –30°C lasted 22 days—a new record. The same pattern was observed in the northern part of the Tomsk region at Aleksandrovskoe, where severe frosts persisted for 24 days, with frosts below –30°C persisting for 23 days.

Record-breaking low minimum air temperatures were recorded in the second 10-day period of January in the eastern parts of the central Chernozem region. By 24 January, severe frosts reached southern regions; in Krasnodar and Adygeia, the recorded air temperatures were –34° and –29°C, respectively. Even on the Black Sea coast, in the vicinity of Anapa-Novorossisk, the air temperature dropped as low as –25°C. The Astrakhan region (Verkhny Baskunchak) experienced the record-breaking low minimum air temperature of –33.3°C. The lowest minimum air temperatures for the whole period of record were observed in Krasnodar (–30.6°C) and Stavropol (–24.3°C). On 30 January, temperatures in Krasnoyarsk dropped to –41.3°C, dropping below the previous daily record of –40°C. In some of the settlements in the Krasnoyarsk Territory, the air temperature dropped as low as –50°C. The lowest temperature in Russia was registered on 30 January in the Evenki Autonomous Area (–58.5°C in the Kerbo Settlement). For comparison, in Oimyakon, the town in Yakutia that is the "cold pole" in the Northern Hemisphere, thermometer readings did not drop below –45.4°C.

In most of European Russia, it was also cold in February. Severe frosts persisted in the southern part of the Evenki Autonomous Area and in the central Krasnoyarsk Territory (1°–2°C below normal). In western Siberia, particularly in the north, February was warm. In the north of the Yamalo-Nenets Autonomous Area, mean monthly temperature anomalies were 6°–8°C. In northeastern Siberia, mean monthly air temperature in February was 3°–5°C above normal. February was also warmer than normal in the Tyva Republic. Maximum positive anomalies (more than 4°C) were recorded in the northwest of the Yakutia-Sakha Republic and in the east of the Chukotka Autonomous Area. In Chukotka, warm weather was accompanied by a large amount of precipitation, frequent snow storms with wind speeds attaining 23–28 and 35–40 m s^{-1} on the coast, and poor visibility. Above-average precipitation was also recorded in the eastern Amur Region, central Khabarovsk Territory, and Maritime Territory, and on the western coast of Kamchatka.

In March, a substantial part of European Russia experienced cold weather: the entire Northwestern Federal District and nearly all of the Central Federal District, except for the Voronezh, Belgorod, and Kursk regions. At the cold center, the anomalies were –6°C. In Ural, warmer weather was accompanied by

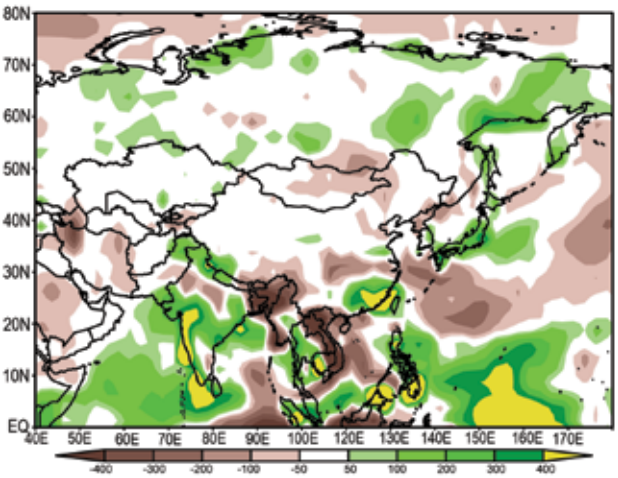

Fig. 6.25. Asian 2006 annual precipitation anomalies (mm, 1979–2000 base) from CAMS-OPI.

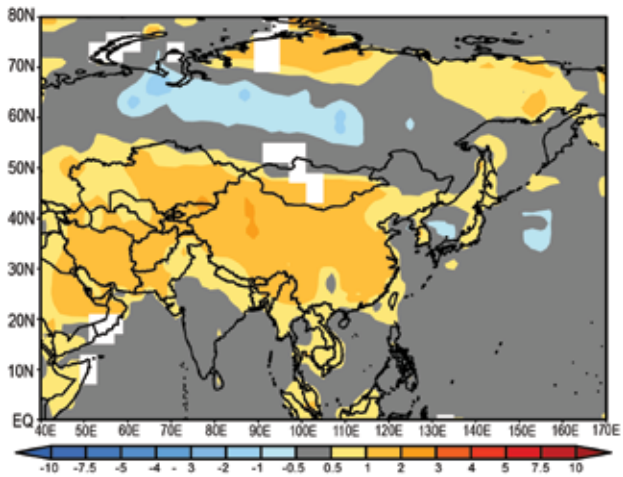

Fig. 6.26. Asian 2006 annual temperature anomalies (°C, 1971–2000 base) from CAMS-OPI.

substantial precipitation (200%–300% of monthly norms). A monthly precipitation norm was also considerably exceeded in the Volga-Vyatka and central Chernozem regions (250%–300%). Very large amounts of precipitation (250%–330% of monthly norms) were recorded in the southern Far East. Particularly intensive precipitation was recorded in Sakhalin and the Maritime Territory in the third 10-day period.

In April, positive temperature anomalies were recorded in most of European Russia. East of Ural, the air temperature was below normal, with temperature anomalies –6° to –8°C in the Yamalo-Nenets Autonomous Area and in the vicinity of the Ob Bay. In southwestern Siberia, cool weather was accompanied by high precipitation (170%–230% of the monthly norm), which, combined with intensive snow melting, caused torrential spring floods in the Kemerovo region and Altai Territory. Particularly serious hydrological conditions were noted on the Biya River near Biysk: about 500 houses were impounded in the town and people had to be evacuated.

Summer began with hot weather. In nearly the entire Russian territory, mean monthly air temperatures in June were above normal. Although temperature anomalies were no higher than 5°C, positive anomalies over most of the Russian territory resulted in 2006 having the warmest June on record (1936–2006). In July, the mean monthly temperature in the west of European Russia was 0.5°–1.0°C above normal. In the northwestern region, from 8 to 12 July, mean daily air temperatures attained 24°–27°C (anomalies of 7°–10°C).

A significant precipitation deficit in the north of the north Caucasus region caused soil drought in most of the Rostov region and the steppe zone of the Kabardino-Balkaria Republic, and allowed soil drought to persist in the southern and Volga areas of the Volgograd region. Soil drought was also recorded in individual regions of the republics of Mordovia, Chuvashia, and Udmurtia. The southern Khabarovsk Territory received more than two monthly precipitation norms, which caused high rainfall floods on the territory's rivers that had not been recorded since 1961.

In August, very hot weather set in the southern Federal District. Mean monthly air temperature anomalies were 5°–6°C. In the first half of the month, air temperatures rose as high as 37°–43°C. On 10 August, air drought started in the steppe regions of north Osetia; the dry period lasted 25–35 days, during which the maximum air temperature exceeded 30°C. Air drought was aggravated by soil drought. On 23–24 August, rains in the north and southeast of the Rostov region stopped soil drought. August in central European Russia proved to be very rainy. The Kaluga, Tula, Oryol, and Ryazan regions received more than two monthly precipitation norms. In Kaluga, August of 2006 was the most humid in the past century.

In the Far East, warm weather prevailed in August. Mean monthly air temperature anomalies in the southern Khabarovsk Territory and in Sakhalin exceeded 3°C. The southeast of the Yakutia-Sakha Republic and the north of the Magadan region and the Khabarovsk Territory experienced very warm weather. However, frequent rains were observed in these regions; some places received more than three monthly precipitation norms. Okhotsk, for example, received 72 mm of precipitation in 12 hours on 15–16 August. September, like in the previous year, proved to be warm in most of the country, though mean monthly air temperature anomalies were lower than those in September 2005.

In the first 10-day period of October, cold weather occurred abruptly in the north of the Irkutsk Region, causing frost conditions. Strong winds and snow caused damage of power transmission lines and power supply failures. For all of October, the northeast of the Far East region experienced a strong heat center, where mean monthly temperature anomalies exceeded 6°C. In November, Russia experienced two large heat foci, divided by a sufficiently intensive cold zone. On the Arctic coast and on the islands, as well as in most of the Far East, November was very warm. The center of this focus was over continental zones of the Magadan region and the Chukotka Autonomous Area. At the center, mean monthly air temperature anomalies were 13°–15°C. In the east and south of Yakutia, the Amur region, the northern Khabarovsk Territory, the north of the Chita region, and the southwest of the Magadan region, warm weather was accompanied by a large amount of precipitation. This is not typical for this season, when the Siberian anticyclone is normally prevailing in these regions. As a result, monthly precipitation norms were exceeded by up to 100%–300% in many places. This November in Magadan, for example, following two very low-snow months of November, 161 mm of precipitation (358% of the monthly normal) was recorded, which is only 5 mm lower than the 1995 absolute maximum.

The end of the year proved to be abnormally warm over most of the Russian territory (Fig. 6.27). The mean monthly air temperature averaged over the territories of the quasi-homogeneous regions (region

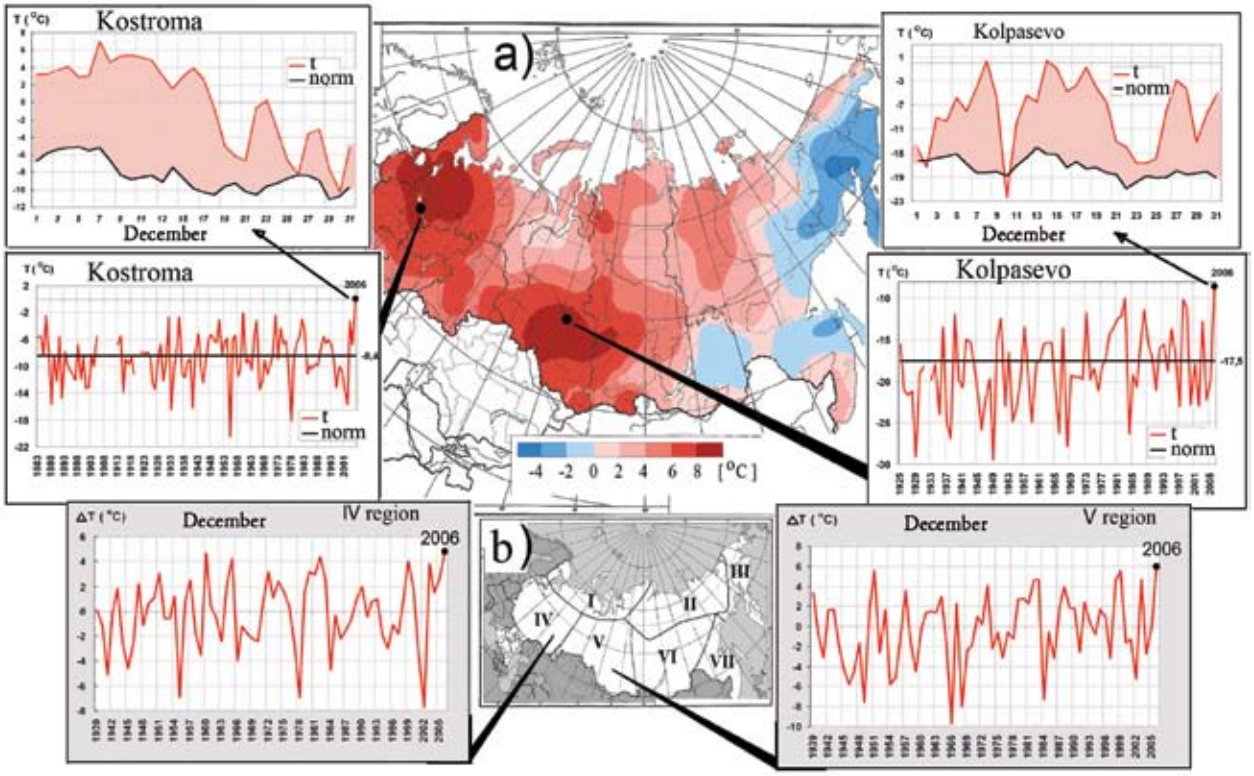

Fig. 6.27. Russian air temperature anomalies (°C) in December 2006. The middle side panels (a) show December mean monthly air temperature series at meteorological stations Kostroma (1883–2006) and Kolpasevo (1925–2006). The upper side panels depict daily air temperature values during December 2006 for these two stations. The lower panels (b) show the December mean monthly air temperatures averaged over quasi-homogeneous regions IV and V.

IV in the center and the south of European Russia and region V in the center and the south of western Siberia) was the warmest on record (Fig. 6.27b). Meteorological stations at the places of positive anomalies registered record-breaking mean monthly air temperatures (Fig. 6.27a). In Moscow, for more than 100 years of observations, the mean December air temperature did not reach such values as in 2006. It was 1.2°C. Mean daily air temperatures were above normal during the whole month, except for 26 December. Daily air temperatures that are maximal for the whole period of record were exceeded 11 times. On 15 December, the maximum air temperature reached 9°C.

2) China—Ling Wang and D. Ye

(i) Temperature

The annual mean temperature of China in 2006 was 9.9°C, which was 1.1°C above the climatology (1971–2000 mean value). The year 2006 was the warmest year since 1951 (see Fig. 6.28). The seasonal mean temperature was also above the climatology in all four seasons, and reached the hottest peak since 1951 in both summer and autumn.

Above-normal temperatures were observed almost throughout the whole country. In the northwest, southwest, western parts of north China, Huanghuai region, the middle and lower reaches of the Yangtze River, and western parts of inner Mongolia, the temperature anomalies were 1°–2°C above normal (see Fig. 6.29). In the winter of 2005/06 (December–February), warmer-than-normal temperatures were observed in most areas of the Tibetan Plateau, where the temperature was 2°–5°C above normal. In summer (June–August), a record-breaking heat wave affected Chongqing and eastern parts of Sichuan. In Chongqing, from mid-July to late August, the number of "broil days" in which the daily maximum temperature was greater than 38°C was 21. This was significantly above the normal of 3.2 days, and reached the maximum in records. In autumn (September–November), above-normal temperatures were observed in most regions of China.

(ii) Precipitation and droughts

In association with the higher temperature,

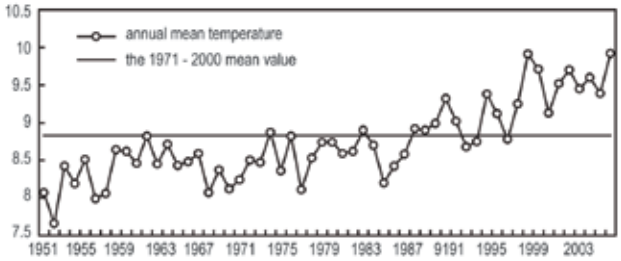

Fig. 6.28. Time series of annual average air temperature (°C) in China, 1951–2006.

China experienced a deficient rainfall year. Below-normal precipitation was observed in most areas of the Yangtze River valley, north China, and western parts of northeast and eastern parts of Inner Mongolia. Rainfall was 10%–50% less than normal in these regions. From June to the first half of November, the Yangtze River valley endured dry conditions, and the average precipitation was the second lowest since 1951, making the river drop to record low levels.

A severe drought occurred in Sichuan Province and Chongqing City during the summer. From June to August, the precipitation over these regions was about 67% of normal, and was the lowest since 1951. Meanwhile, due in part to the heat wave, Chongqing and Sichuan endured the worst drought since 1951: about 3.38 million ha of crops were damaged. Total losses were estimated at 19.3 billion RMB.

Eastern parts of China experienced warmer and drier conditions during autumn. The precipitation was 50%–80% less than normal in north China, Huanghuai region, and western parts of south China during September to the first half of November. In addition, higher temperatures were observed almost throughout the country. This condition enhanced the soil water evaporation and caused a large-scale drought over eastern China. More than 6.4 million ha of crops were affected, particularly in Shandong and Guangxi Provinces.

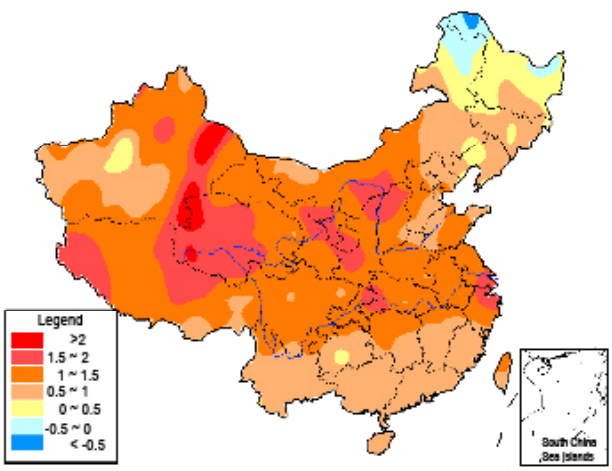

Fig. 6.29. Annual air temperature anomalies (°C) over China in 2006.

(iii) Floods and heavy rainstorms

Heavy rainstorms during 2–10 June affected southern China, where the accumulated precipitation was about 100–300 mm. It reached 500 mm on Shanwei, on the eastern coast of Guangdong Province. During 12–13 June, extremely heavy rain occurred in Wangmo County in the southern part of Guizhou Province. The 4-hour accumulated precipitation reached 196 mm, causing severe mountain torrents and mudslides, leading to 30 deaths. During 5–13 October, heavy rain continued to control the south-central parts of Yunnan Province, and brought 100–300 mm of precipitation, which is 100%–200% more than the October normals.

(iv) Tropical cyclones

In 2006, there were 24 tropical cyclones with at least tropical storm intensity in the western North Pacific, this was below the 1971–2000 average of 27. Six of them made landfall in China (the average of seven). The first landfalling typhoon, Chanchu, was earlier than normal by 40 days. It is the earliest typhoon to directly strike Guangdong since 1949. From July to August, five tropical cyclones made landfall in China one after another, with strong intensity, causing devastation. In autumn, no tropical cyclones made landfall, which is also a rare occurrence. There were 1522 deaths caused by tropical cyclones in China during 2006 (the most deaths in 10 years). Associated with the southwesterly monsoon, Tropical Storm Bilis killed 843 people. Supertyphoon Saomai was the most powerful typhoon to strike China since 1949; it directly struck Zhejiang Province with a maximum wind near the center of 60 m s^{-1} and a minimum pressure of 920 hPa, resulting in 483 fatalities.

(v) Dust storms

In spring of 2006, 18 dust weather events occurred, including 5 strong dust storms. The number of dust events reached the maximum since 2000. The strongest dust storm occurred on 9–11 April, affecting 13 provinces in northern China; Tulufan Basin in Xinjiang Province witnessed the most intense dust storm in the past 22 years. Another dust storm happened on 16–18 April, which affected about 1.2 million km^2, with large impacts in Beijing.

3) Southeast Asia—W. Li and Y. Zhu

(i) East Asian monsoon

The East Asian summer monsoon onset commenced over the SCS in the fourth pentad of May, which is near normal, and the flow remained southwesterly over regions from South China to the Jiangnan area before the third pentad of June. During the fourth pentad of June, with the subtropical high skipping northward, southwesterly flow advanced to the Huanghuai area. Meanwhile, the 340-K isoline of potential pseudoequivalent temperature moved northward and remained north of 35°N from July to the first decad of August. During the fourth pentad of August, the 340-K isoline retreated southward quickly to 30°N, and to 20°N during the first decad of September. During the second pentad of October, the 340-K isoline withdrew from the SCS, which indicated that the warm and humid air had withdrawn from the SCS. Meanwhile, at the 850-hPa level, wind flow over the SCS changed 180° to become northeasterly. This indicated that the SCS summer monsoon came to an end during the second pentad of October 2006, which was later than normal.

The SCS summer monsoon index was −0.79 in 2006, which was weaker than average. Pentad intensities of the SCS summer monsoon were weaker than normal during most of the time (Fig. 6.30). During the summer of 2006, rainfall totals were more than normal in South China, Huanghuai area, and mid-northern northeast China, while they were less than normal in the mid–lower reaches of the Yangtze River.

(ii) Temperature

Generally, monthly mean surface air temperatures were slightly above normal (1971–2000 mean) in most regions of Southeast Asia during December 2005–November 2006. Seasonal mean surface air temperatures were above normal in most of Southeast Asia during winter (December 2005–February 2006) and autumn (September–November), with departures exceeding 1°C in the northern Indo-China peninsula during boreal winter and in the eastern Indo-China peninsula during boreal autumn. Generally, temperatures were near normal across Southeast Asia throughout the remainder of the year.

(iii) Precipitation

Generally, precipitation was above normal across the western Indo-China peninsula and below normal in the eastern Indo-China peninsula from December 2005 to November 2006. During winter, rainfall totals were 50%–100% above average in the western Indo-China peninsula. Meanwhile, heavy amounts of rain associated with the northeast monsoon contributed to significant flooding across the central Philippines and parts of the Malay peninsula. In spring, precipitation was ~50%–100% above average in the northwestern Indo-China peninsula. June–August precipitation was close to normal, though heavy rainfall associated with the monsoon affected Vietnam, Cambodia, and the Philippines. During autumn, rainfall totals were 30% to 50% below average in the eastern Indo-China peninsula, and near normal elsewhere.

(iv) Notable events

In the Philippines, heavy rainfall induced deadly landslides in southeastern Philippines during the second decad of February 2006; there were at least 139 confirmed fatalities. Typhoon Chanchu crossed the Philippines during 11–13 May and produced torrential rain, causing 41 deaths and leaving thousands homeless. Typhoon Xangsane crossed the Philippines during 27–28 September and was blamed for 110 deaths. Typhoon Durian struck the northern Philippines on 30 November, with at least 406 fatalities. Across eastern Indonesia, landslides and floods caused by torrential rain on 21 February killed at least 33 people in the city of Manado. Monsoon-related rainfall produced flooding in east Java during mid-April, and was blamed for at least 23 deaths. Floods and landslides ravaged eastern Indonesia on 19–20 June, causing about 200 fatalities. In Malaysia during the mid-December 2005, flooding killed at least 9 people, and over 17,000 people were driven into relief shelters.

During the third decad of May, heavy rainfall brought devastating flooding and mudslides to parts of northern Thailand. More than 100 people may have died in flash floods. In Thailand during early October, heavy rainfall in the wake of the remnants of Typhoon Xangsane was responsible for 32 deaths across the country, and affected 1.8 million people.

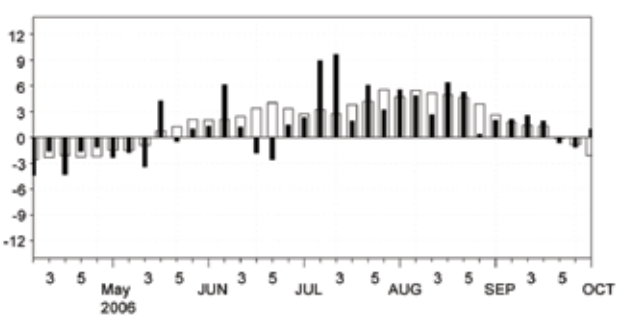

Fig. 6.30. Variation of the zonal wind index over the South China Sea (m s^{-1}).

Monsoon-related flooding in central and northern regions of Vietnam was blamed for 42 deaths during August. Typhoon Xangsane made a final landfall in central Vietnam in October; there were 68 deaths and nearly 320,000 homes were destroyed or submerged.

4) South Asia—M. Rajeevan and Jayashree Revadekar

The year 2006 was marked by extreme weather across South Asia, both in terms of precipitation and temperature. In January, many parts of South Asia experienced severe cold wave conditions with minimum temperatures dipping below normal by more than 4°C. Minimum temperatures hovered around the freezing point at some stations like Amritsar (–2°C on 7 January), Srinagar (–7°C on 11 January), and Ganganagar (–1°C on 8 January). Frost was observed in New Delhi for the first time in 70 years as cold air sweeping in from the Himalayas produced a low temperature of 0.2°C on 8 January. Over north India, more than 150 deaths were attributed to cold weather conditions. In neighboring Bangladesh, unusually cold weather also claimed some lives during the same period. However, in February, many parts of South Asia experienced unusually warm temperatures, which severely affected the winter crops over this region. During the month, mean temperatures were 5°–6°C warmer than normal over northern parts of India and adjoining Pakistan and Afghanistan. More than 30 stations reported the highest maximum temperatures ever recorded for the month of February, even some 100-year records. At Allahabad, the monthly mean maximum temperature in February was 36.3°C, breaking the previous record set in 1896.

Before the southwest monsoon sets in, heat waves are common in May and June over northern parts of India and Pakistan. During the second week of May, severe heat wave conditions prevailed over northwestern parts of India, with daily maximum temperatures above normal by 6°C, claiming more than 50 lives. At some stations, temperatures reached 45°C. Over India, mean temperatures were consistently above normal during all the months, except in June. The year 2006 was the warmest year on record since 1901, with the annual mean temperature above normal (1961–90) by 0.59°C. In January, snowstorms and flooding affected major parts of Afghanistan, claiming many lives. Badakhstan was among the worst hit provinces when snowstorms moved over this region. During April, flooding due to snowmelt and seasonal rainfall affected numerous provinces of Afghanistan-like Faryab and Baghlan. On the other hand, drought conditions and severe water stress prevailed over some parts of Pakistan, especially in Balochistan, due to inadequate rainfall during the winter and spring seasons.

(i) South Asian summer monsoon (June–September)

The summer monsoon season (June–September) is the main rainy season over a major portion of South Asia, contributing 60%–90% of annual rainfall. The onset phase of the 2006 monsoon season was characterized by an early monsoon onset over the south peninsula (26 May). However, after the first active spell associated with monsoon onset, there was a prolonged hiatus of about 16 days, due to southward intrusion of stronger midlatitude westerlies and enhanced convection over the equatorial Indian Ocean. During this period, the advance of the monsoon over northern and northwestern parts of India was delayed. The monsoon revived during the last week of June and it finally covered northwestern parts of India and Pakistan during the last week of July, about 10 days later than its normal date.

Breaking the declining trends observed over the past few years, a revived occurrence of low pressure systems typical of the summer monsoon was observed this year. As many as 16 low pressure systems formed over the Indian region, 12 over the Bay of Bengal, 1 over the Arabian Sea, and 3 over land. Of these 16 low pressure systems, 8 (the highest since 1997) intensified into monsoon depressions and 1 into a cyclonic storm (Mukda). In August, four monsoon depressions formed over the Bay of Bengal, which is a record since 1891. The monsoon depressions formed over the Bay of Bengal moved more in a west-to-northwesterly direction, very much south of the normal track position, thus giving copious amounts of rainfall over central India. The remnants of these systems then moved over extreme northwest India and adjoining Pakistan.

The all-India summer monsoon seasonal rainfall was near normal (100% of its long period average). However, rainfall was not well distributed over space and time. After the first spell of active rainfall activity associated with the onset phase, the monsoon was more or less subdued over the country until the third week of July. As of 26 July, cumulative all-India seasonal rainfall departure was only 87% of its long period average. However, the monsoon revived rapidly during the last week of July and remained active over India and Pakistan almost until the end of September. In August, all-India rainfall was 6% above its long period average and in September, it was 2%.

During this season, out of 36 meteorological sub-

divisions of India, 6 received excess rainfall, 21 received normal rainfall, and the remaining 9 received deficient rainfall. About 60% of the 533 meteorological districts received excess/normal rainfall and the remaining 40% received deficient or scanty rainfall. About 25% of the districts experienced moderate drought and 30 districts (6%) experienced severe drought conditions on a seasonal scale. During the second half, the seasonal trough (monsoon trough) was confined mainly south of its normal position and all the low pressure systems moved across central India along the monsoon trough. Due to this, central India received excess rainfall by 16%, while seasonal rainfall over northeastern parts of India and adjoining Bangladesh was below normal by more than 15%. However, northwest and southern parts of India received normal rainfall during the season (Fig. 6.31). Over Nepal, rainfall activity was below normal by more than 20% in July and August. Rainfall activity picked up only in September, during which the monthly rainfall was above normal.

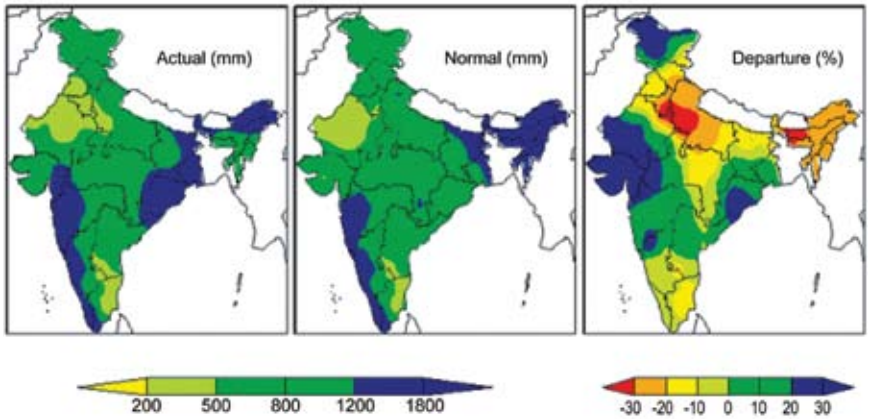

Fig. 6.31. Seasonal rainfall patterns during the 2006 summer monsoon season. [Source: http://soman.tropmet.res.in/mol.]

Pakistan experienced moderately above normal rainfall (27.2%) during the monsoon season (July–September). The province of Punjab received normal rainfall (1.5%) and the provinces of NWFP and Balochistan experienced slightly above normal rainfall (22.0% and 12.4%, respectively). The province of Sindh had received largely above normal rainfall (116.6%). Another interesting aspect of this season was the occurrence of extreme rainfall events. In many places, many heavy rainfall events occurred, causing localized but severe flooding. The unprecedented heavy rains and destructive flooding across much of South Asia, including Afghanistan, Pakistan, India, and Nepal, affected more than 5 million people and resulted in more than 1000 deaths. During the third week of August, unusually heavy rainfall in the Thar Desert over northwest India caused devastating floods. During the period 16–25 August, 549 mm of rainfall was recorded over this region, which destroyed thousands of hectares of standing crops.

(ii) Northeast monsoon

The northeast monsoon (October–December) contributes 30%–50% of annual rainfall over southeastern parts of India and Sri Lanka. During the 2006 northeast monsoon season, heavy rainfall continued unabated over these regions especially during October and December. In India, the states of Tamil Nadu and Andhra Pradesh were the worst affected. However, the season known for tropical cyclone activity, witnessed only one tropical cyclone (Ogni), which affected parts of Tamil Nadu and Andhra Pradesh. Most of the rainfall activity during the season was associated with the movement of easterly waves. The associated floods in southeast India and Sri Lanka affected more than 1 million people with at least 100 fatalities and had a considerable socioeconomic impact. Over these regions, the northeast monsoon seasonal rainfall was above normal by more than 15%.

5) Southwest Asia—F. Rahimzadeh and M. Khoshkam

Anomalously warm and cold seasonal temperature was observed across the region this year. Temperature patterns varied in time and space. Warmer-than-average temperatures occurred in winter and spring (about 1°–2°C above average). Cooler-than-average and wetter-than-average conditions occurred in the western half of Iran during autumn.

(i) Winter

Temporal and spatial temperature variability was intense in winter (2005/06). Iran experienced anomalously warm temperatures in February. On average, winter temperatures were 2°C above that of the long-term. Parts of central and northeastern Iran were 2°–3°C cooler than normal. The areas with precipitation amounts near normal or above were the west, southwest, northwest, and Alborz Mountains, while the rest of the area had precipitation

amounts of 75% of normal or less. The range of winter precipitation was 1250 mm. The largest amount of precipitation was observed near the Zagros Mountains (Koohrang 1250 mm) in western Iran, and the lowest (5.9 mm) in southeastern Iran. Winter precipitation was 28% less than 2005, and 6% less than the long-term average. Much of the precipitation falls as snow, especially in December and January. Heavy rainfall brought flooding to parts of the southern provinces during February 2006, creating serious transportation problems for the mountain and cold provinces.

(ii) Spring

Spring temperatures were mostly 0°–2°C above normal over most parts of Iran. A few exceptions were Fars, Kerman, Yazd, and the south, which was 2°C cooler, as well as a few places that were up to 4°–6°C warmer than the long-term spring averages. The seasonal mean temperatures ranged from 10°C in the northwest to 35°C in the southeast. Precipitation totals across the southeast of the country were only 0%–25% of the long-term mean, whereas wetter-than-average conditions prevailed over the central region, which received 100%–260% of its long-term average precipitation. The northwest region received 50%–100% of normal rainfall. In general, precipitation increased with respect to 2005, but was 14% lower than the long-term mean in spring.

(iii) Summer

Summer was cooler than average over one-fourth of Iran (in the central and eastern provinces) while above-average temperatures were observed in the rest of the country, with averaged departures 2°C above normal. Many parts including central, eastern, and some parts of the southwest received no measurable rainfall. Averaged precipitation was below normal in the summer of 2006, 5% lower than 2005, and 24% lower than the long-term mean. Areas with precipitation amounts of 75% normal to near normal were parts in south, southeast, northeast, and northwest. Dust and sandstorms occurred in the Sistan and Balochestan provinces in southeastern Iran, western Afghanistan, and Pakistan.

(iv) Autumn

In autumn, cooler-than-average conditions persisted across southern and central Iran; warmer-than-average conditions were limited to parts in the eastern provinces. Cold temperatures affected many areas during autumn, with many locations breaking their all-time record minimum temperatures for the season. Averaged across the nation as a whole, it was one of coldest autumns in decades. A severe cold wave, which arrived during early December, brought some of the coldest temperatures to the region in decades. Parts

COUNTRY SPOTLIGHT: TURKEY—S. Sensoy

The annual surface temperature anomaly averaged over Turkey in 2006 was 0.9°C above the 1971–2000 average (Fig. 6.32). Only one station (Solhan) in the eastern part of Turkey had annual temperatures below average (–0.59°C). Generally, western parts of the country had annual temperatures near average while eastern parts were above the mean. Positive temperature anomalies have been reported since 1994 (except 1997). The number of summer days ($T_{max} \geq 25$°C) have been increasing all over Turkey while ice days and frost days have decreased. Temperatures in January, November, and December were below average. Between February and October, temperatures were near and above average. Significant positive temperature anomalies ($p \leq 0.05$) occurred during the summer season (JJA).

Due to Turkey's topography, rain clouds seldom penetrate the country's interior. Rain clouds drop most of their water on the slopes opposite the sea. For this reason, the central Anatolia does not have very much precipitation. While Rize receives 2200 mm of precipitation annually, Konya receives only 320 mm. Average annual total precipitation for Turkey is 632 mm according to the 1971–2000 base periods (Sensoy 2004). The average total precipitation in 2006 was 606 mm, slightly below average. Western parts of Turkey and the Çukurova Plateau had been suffering prolonged drought conditions. Approximately 150 stations received less precipitation than average in the winter, spring, and summer seasons. Despite these dry conditions, flood events occurred in some places. Ten people died in Diyarbakir in October from flooding.

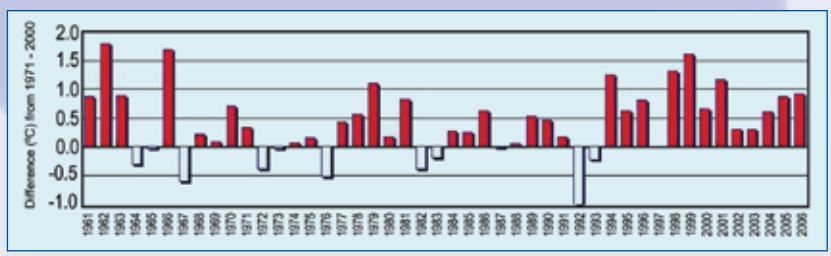

Fig. 6.32. Time series of Turkish annual average air temperature anomalies (°C; 1971–2000 base) from 1961–2006.

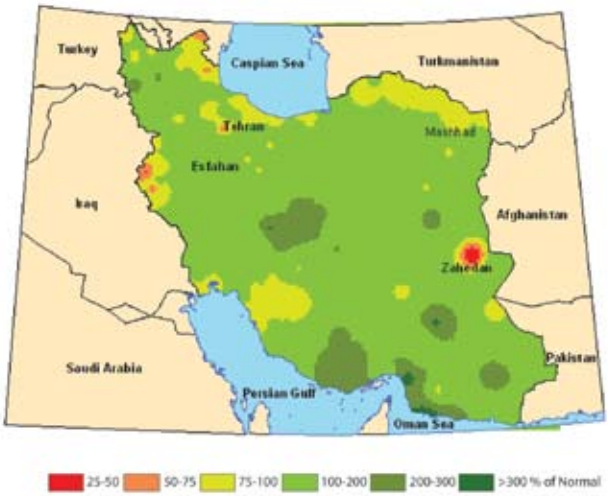

Fig. 6.33. Autumn precipitation anomalies (%) over Iran. [Source: I.R. of the Iran Meteorological Organization.]

of Iran were up to 8°C cooler than normal during December. Snow and cold weather penetrated northern Iran, with heavy rainfall in eastern and southern Iran. For the country, the average of precipitation in autumn was 83 mm. The largest anomalies were recorded in Hormozgan Province, with 2.2 times the normal precipitation (Fig. 6.33). From a seasonal perspective, precipitation totals were normal to above normal in much of Iran during autumn 2006.

(v) Significant weather events

Significant weather events included drought, heat and cold waves, flooding, and dust and sandstorms. Floods occurred in northern Iraq in February and November, in Turkey in July, in Pakistan from late July through mid-August, in Afghanistan in August and November, and in Iran's Ardebil Province in May. Heavy rain triggered mudslides in Tajikistan in May and in northern Pakistan on 3 July. In addition, significant drought continued throughout some parts of the region. For example, significant drought across Afghanistan occurred in July as rainfall had been lacking since April 2006. Dust storms blew and spread out over a wide area, covering some parts of Afghanistan, southeastern Iran, and western Pakistan during summer and autumn. Other extreme events, such as a severe winter storm accompanied by heavy snowfall in some provinces of Afghanistan, and near Dushanbe in Tajikestan, caused economic losses.

g. Europe and the Middle East

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

CAMS-OPI precipitation and air temperature anomalies over Europe are shown in Figs. 6.34 and 6.35, respectively. Europe experienced above-normal temperature anomalies across nearly the entire continent in 2006.[6] For the 35°–75°N and 10°W–30°E region the annual average land surface temperature was 1.15° ±0.08°C above the 1961–90 average (based on CRU TEM3; Brohan et al. 2006). The annual average near-surface temperature, incorporating land and sea surface temperatures, was 0.93 ±0.05°C above the 1961–90 mean (Fig. 6.36). The highest positive annual anomalies of more than +4°C were found in

[6] Contributing countries (national meteorological and hydrological services) to this section are Armenia, Austria, Bulgaria, Cyprus, Denmark, Finland, France, Germany, Iceland, Italy, Kazakhstan, Lithuania, Norway, Portugal, Romania, Russia, Spain, Sweden, and the United Kingdom.

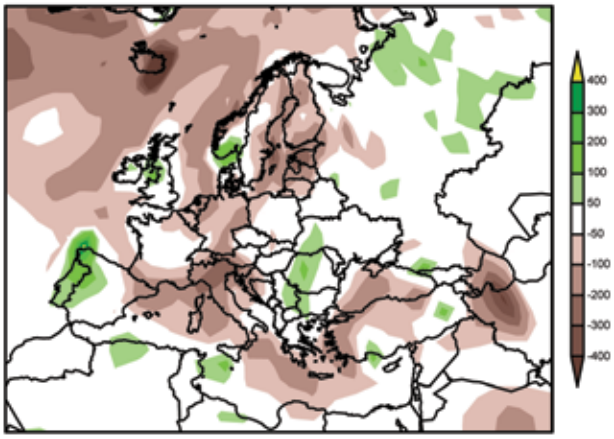

Fig. 6.34. European 2006 annual precipitation anomalies (mm, 1979–2000 base) from CAMS-OPI.

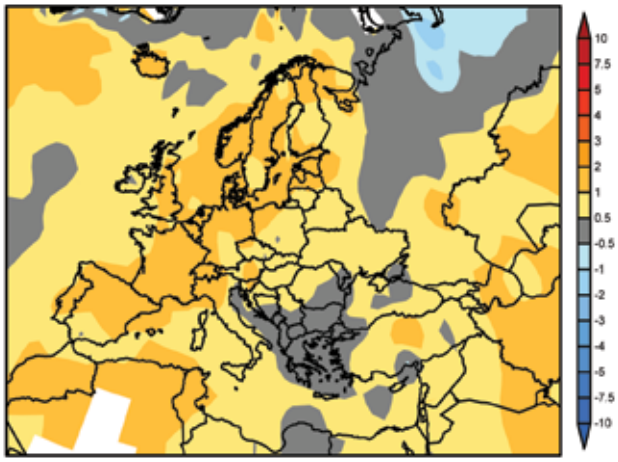

Fig. 6.35. European 2006 annual temperature anomalies (°C, 1971–2000 base) from CAMS-OPI.

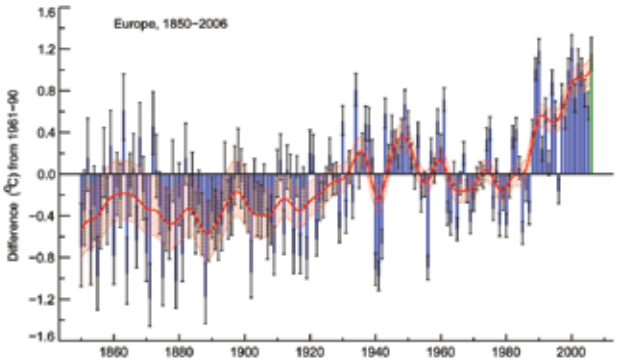

Fig. 6.36. Time series of area average land surface temperatures over Europe (35°N–75°N, 10°W–30°E) from 1850 to 2006 (data are from Brohan et al. 2006). The blue bars show the individual annual values and the thin gray bars indicate the two standard error range on the annual values. The value for 2006 is shown in green. The smooth red curve and shaded area show the annual values after smoothing with a 21-point binomial filter and represent roughly the interdecadal variability in the data and its uncertainty.

northern parts of Greenland and around Svalbard. Large parts of Scandinavia, northwestern, western, and central Europe, and even most parts of the Iberian Peninsula experienced anomalies above +1°C, exceeding the 90th percentile in many areas, and the 98th percentile in more limited areas in the HadCRUT3 dataset. The United Kingdom, Spain, and the Netherlands reported their warmest years in recorded history. The eastern parts of Europe had smaller anomalies of less than +1°C. Slight negative anomalies (down to about −0.5°C) were only registered locally in southern and southeastern Europe. Seasonal temperature anomalies in Europe increased throughout the year from winter 2005/06 through to autumn 2006.

Precipitation amounts for the climatological year of 2006 (December 2005–November 2006) were generally above average in eastern and southeastern parts of Europe, with anomaly maxima over the Arctic islands, and in Greece and southern Italy, while wide areas over the western part of Europe received below-average rainfall. Areas receiving less than 80% of normal precipitation amounts were restricted to the region between the Alps and the Pyrenees, and southern Spain, as well as some coastal regions in the north. Precipitation anomalies averaged over 2006 were generally lower than those in 2005. However, the seasonal variation throughout the year was quite high.

2) Nordic region—C. Achberger, J. E. Box, and D. Chen

Weather and climate conditions in the Nordic region (comprising Sweden, Norway, Denmark, Finland, Iceland, and Greenland) are characterized by a continued pattern of warm anomalies in observational records for 2006 as compared to recent decades. The Fennoscandinavian countries (Norway, Sweden, Finland, and Denmark) and Iceland experienced a warm summer and an extremely warm autumn. Surface climate conditions in this area are to a large extent controlled by the atmospheric circulation over northern Europe and the North Atlantic region. Synoptic weather typing, according to the scheme by Lamb (1950), has been used to estimate the impact of the large-scale atmospheric circulation on the surface weather conditions in this region (e.g., Chen 2000). Compared to the 1961–90 mean, the frequency of daily southwesterly and westerly weather types were above normal, which can explain the warmer-than-normal conditions in 2006. Positive deviations from the normal weather-type distribution are especially obvious during autumn, with stronger-than-normal large-scale flow from westerly and southerly directions and increased number of anticyclonic days. These flow conditions in autumn are consistent with the warm and wet weather that prevailed in extended parts of Fennoscandinavia.

(i) Fennoscandinavia and Iceland

Annual temperatures in Fennoscandinavia and Iceland were, on average, well above the long-term means for 1961–90: 1°–2.5°C depending on the region (Fig. 6.37). For Denmark, 2006 was the warmest year since 1874. The annual mean temperature was 1.7°C above the 1961–90 mean. For Norway, 2006 was one

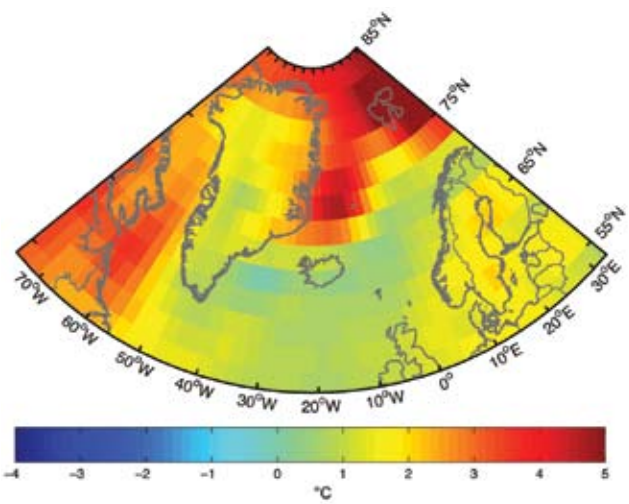

Fig. 6.37. 2006 annual air temperature anomalies (°C; 1961–90 base) across Fennoscandinavia, the North Atlantic, and Greenland. [Source: NCAR–NCEP reanalysis.]

of the three warmest years in the country's temperature record (behind 1934 and 1990). Some Norwegian regions experienced their largest positive deviations from the long-term mean (1961–90), such as Svalbard (+5°C) as well as parts of the county of Trøndelag and the southern regions of northern Norway (+2°–3°C). In Sweden, 2006 was also a very warm year. The annual mean temperature was only 0.3°C below the warmest year, as 2006 ranked as the sixth warmest year during 1860–2006. The Finnish annual mean temperatures were among the 10th–15th highest since 1900. Iceland experienced a warm year. Several selected Icelandic stations reported annual mean temperatures placing 2006 among the 5th to 13th warmest year since about 1870.

Iceland and Norway experienced a rather mild start to the year, with temperatures above the 1961–90 mean, in contrast to Denmark, Sweden, and Finland. Spring was characterized by unusually cold weather in March, occurring almost everywhere in the region. Summer temperatures were well above the long-term mean nearly everywhere. Many very hot days (air temperature > 30°C) were reported in Finland. Norway had its fourth warmest summer since 1900. July temperatures in Denmark were nearly 4°C higher than normal. Swedish summer temperatures were also higher than normal. Temperatures at Svalbard airport were more than 2°C above normal, which made 2006 the second warmest summer since measurements commenced in 1912. The warm summer was followed by an unusually warm autumn in most parts of the Nordic region, especially in Denmark where the monthly mean temperatures from September to December were 3°–5°C above normal, reaching new records. Finland experienced unusually warm weather from the second half of November through the end of 2006. In Helsinki, the monthly mean temperature in December was 4°C, the highest since 1929. In Sweden, September and December were extremely warm.

In some parts of the region, precipitation conditions deviated considerably from the 1961–90 average, especially in western Norway and the Norwegian west coast, which were drier than normal. In contrast, precipitation in Sweden and Denmark were well above normal values. For Sweden, 2006 became the sixth wettest year since 1860. Finland's annual precipitation was close to normal or slightly above. Iceland got rather normal amounts of precipitation, though the southwest of the island had somewhat wetter-than-normal conditions. In several areas, the summer was either rather dry and/or rainfall was unequally distributed over the summer months. Southern and western Finland experienced their driest summers ever recorded. In Sweden, farmers had problems because of the lack of rain in June and July, but heavy thunderstorms and strong showers in August led to serious flooding in many places in southern and middle Sweden. Conditions in Denmark were similar, with only half of its normal rainfall amount in July, but August had 100% above-normal precipitation. Norwegian summer precipitation was below normal for most of the country, but strong showers led to damage from flooding at some places. The Icelandic summer was rather wet with stormy weather during July. Wet conditions continued during autumn in many regions. For example, southern Norway received precipitation well above the normal. Heavy thunderstorms in October brought large amounts of rain to many coastal areas in Sweden, while strong and extended rainfall events in December caused serious flooding in southwestern Sweden. Finland got part of its autumn precipitation as snow, leading to all-time high values of snow cover in southeastern parts of Finland in the beginning of November.

(ii) Greenland

(a) *Upper-air temperatures*

Upper-air soundings available from the IGRA (Durre et al. 2006) indicate a complex vertical pattern of warm tropospheric and stratospheric cold temperature anomalies surrounding Greenland (not shown), compared to the 1971–2000 base period. The general pattern of lower-tropospheric warm anomalies accompanied by cold anomalies near the maximum height of the observations (< 100 hPa) is consistent with overall 1964–2005 warming trends (Box and Cohen 2006). In the lower troposphere, still well above the surface at the 850-hPa level (1.1–1.5-km altitude), for example, annual temperature anomalies were between +0.9° and +3.1°C at six sites surrounding the island. Over east-central and southeastern Greenland at Ittoqqortoormiit/Scoresby Sund and Tasiilaq, respectively, a general pattern of lower-tropospheric warm anomalies is evident with the exception of spring, perhaps influenced by above-normal sea ice concentration (see section 5b). At the upper limit of mandatory observational levels (20 hPa), relatively large (–7.1° to –8.6°C) cold anomalies are evident in the balloon observations but are not abnormal considering relatively large lower-stratospheric temperature variability (e.g., Christy and Drouilhet 1994). What else stands out are +2.4° to +6.6°C warm anomalies centered at 200 hPa in winter for all sites surrounding but Narsarssuaq in the extreme south. Other regional patterns of note include warm anom-

Table 6.1. Greenland station surface air temperature statistics: 2006 versus 1971–2000.

Station Region	Latitude/ longitude	Statistic	Winter	Spring	Summer	Autumn	Annual
Aasiaat/ Egedesminde	68.7°N	Anomaly (K)	3.9	**4.8**	**1.2**	1.0	**2.7**
West	52.8°W	Rank	7	2	6	8	4
Nuuk	64.2°N	Anomaly (K)	2.1	**2.7**	0.9	0.8	**1.6**
Southwest	51.8°W	Rank	11	3	7	11	5
Prins Christian Sund	60.0°N	Anomaly (K)	1.5	**1.5**	**1.1**	0.6	**1.2**
South	43.2°W	Rank	7	3	4	11	4
Tasiilaq	65.6°N	Anomaly (K)	1.8	0.4	0.6	0.0	0.7
Southeast	37.6°W	Rank	4	16	10	22	11
Danmarkshavn	76.8°N	Anomaly (K)	**3.6**	**2.9**	**-0.5**	1.4	**1.8**
Northeast	18.7°W	Rank	4	3	32	8	2

Bold values indicate *Z* scores that meet or exceed one absolute magnitude.

alies below 500 hPa in Autumn (September–November) at Pituffik/Thule AFB, including apparently extreme, but probably erroneous, +7.9°C at 850 hPa for September–November 2006, given disagreement with MSU4 data (J. Christy 2007, personal communication). Another relatively large (+8.5°C) December 2005–February 2006 anomaly at Aasiaat/Egedesminde may also result from observational error. The potentially erroneous seasonal anomalies at these two sites also affect the annual anomalies.

(b) *Coastal air temperatures*

During the last 56 years (1951–2006), when continuous surface air temperature records are available from a collection of stations around the island (Cappelen et al. 2007), the only significant annual anomalies indicate higher-than-normal surface air temperatures (Table 6.1). In 2006, seasonally, for western and southern sites, like in 2005, spring stood out as being warmer than normal. At eastern sites, cold spring anomalies are evident and are significant seasonally, but not enough to effectively cancel the warmer annual anomalies. Eastern winter anomalies were positive, yet eastern summer temperatures were much lower than normal. Eastern glacier melt rates are likely to have been below recent years in 2006, apparently owing to the eastern coastal cooling effect of April–June positive sea ice anomalies. Western and southern summer temperatures imply continued enhanced glacial melting as sea ice is absent in southwestern Greenland at this time of year. Considering the past century at sites around Greenland where long-term records are available (such as Nuuk and Tasiilaq), the 1930s–40s air temperatures rival recent warm temperatures and suggest that recent extreme melt rates are not without precedent.

3) Iberia—R. M. Trigo, R. Garcia-Herrera, D. Paredes, and A. Ramos

(i) Temperature

The Iberian Peninsula registered temperatures above the average throughout the year, with the exception of winter (Fig. 6.38). The annual average 850-hPa temperature across Iberia in 2006 was 1.14°C above normal (with respect to the 1961–90 period average). This significant positive annual anomaly occurred despite the early negative anomaly for the winter (–1.16°C) that was followed by an extremely hot spring (+2.38°C), and a warm summer (+1.50°C) and fall (+1.84°C). It should be stressed that the annual average temperature for 2006 was the hottest in Madrid (since 1900) and Barcelona (since 1925). The corresponding analysis of the associated upper-level 500-hPa geopotential height anomaly field in winter shows intense positive anomalies between the Azores archipelago and northern Europe, while southern Europe is characterized by lower-than-usual values (Fig. 6.38; DJF). Southwestern Europe and northern Africa were under the influence of strong cold-air advection from higher latitudes. Several cold spells

affected Iberia in January and February.

In particular, a strong cold break was observed in late January affecting all of Iberia, as well as France and central Europe. This cold plume reached Lisbon, Portugal, on the western coast of Iberia, producing a number of days with both maximum and minimum temperatures below the 10th percentile of daily long-term records. On 29 January the cold break was responsible for the first snow episode in Lisbon since 2 February 1954!

Unlike winter, the remaining seasons were characterized by warmer-than-normal temperature values, particularly between late May and November, where parts or the entire Iberian Peninsula were affected by five intense heat waves between May and September. These three seasons were generally characterized by high values of 500-hPa geopotential height, with maximum anomalies located in southern (spring), northern (summer), and eastern (fall) Europe. These patterns contributed to the advection of warm air masses with origins from overheated Eurasia and/or northern Africa. Moreover, these intense anticyclonic patterns can induce subsidence over Iberia associated with further heating of the surface layers through enhanced adiabatic heating (Trigo et al. 2005).

(ii) Precipitation

Most of the Iberian Peninsula experienced drier-than-normal conditions during the winter of 2006, as is clearly shown by the seasonal precipitation percentages computed with respect to the 1961–90 base period average. Based on the monthly precipitation dataset from GPCC (Rudolf et al. 2005) it is possible to see that such winter drought conditions affected a much larger European region, with the exception of the western Mediterranean (and northern Africa). From an atmospheric circulation perspective, the 2006 winter was characterized by positive (negative) SLP anomalies north (south) of the Azores–Iberia latitudinal band, inducing the negative (positive) precipitation anomalies mentioned. It should be stressed that the Iberian Peninsula registered one of the worst droughts ever recorded during 2005, particularly in its southern half (Garcia-Herrera et al. 2006). The dryness of yet another winter season had a strong impact on water resources, hydroelectric production, and agriculture. However, the remaining seasons of the year unfolded very differently from winter, with western Iberia characterized by normal (spring), above-normal (summer), and extremely high values (fall) of precipitation. In fact, Portugal, located in western Iberia, registered the third wettest fall since 1931 (Espirito-Santo 2006), with most of the country showing values above 200% of the seasonal average. The spring and fall seasons correspond to the two most important rainfall seasons for northern and eastern Iberia (Trigo and Palutikof 2001). Interestingly, both spring and fall seasons were characterized by negative anomalies of SLP over the Atlantic Ocean and northern Europe. However, the amplitude of these negative anomalies was deeper during fall (compared to spring), and covered the entire Iberian Peninsula, which is related to the intense positive precipitation observed. Nevertheless, the Mediterranean coastal sector, including southern France, eastern Spain, and northern Africa, remained mostly dry between spring and fall. Therefore, at the end of 2006, several Spanish provinces located close to the Mediterranean coast were extremely dry as a consequence of more than two consecutive years with precipitation below the 1961–90 average.

4) Central Europe and the Alpine region—A. Obregón, P. Bissolli, and J. J. Kennedy

(i) Temperature

Annual average temperatures in the region were significantly above average (upper decile of the 1961–90 distribution). Central Europe and the Alpine region experienced one of its warmest years on record with several record-breaking months and seasons. The annual mean temperature of Germany was 9.5°C, which is 1.3°C above normal. Annual average

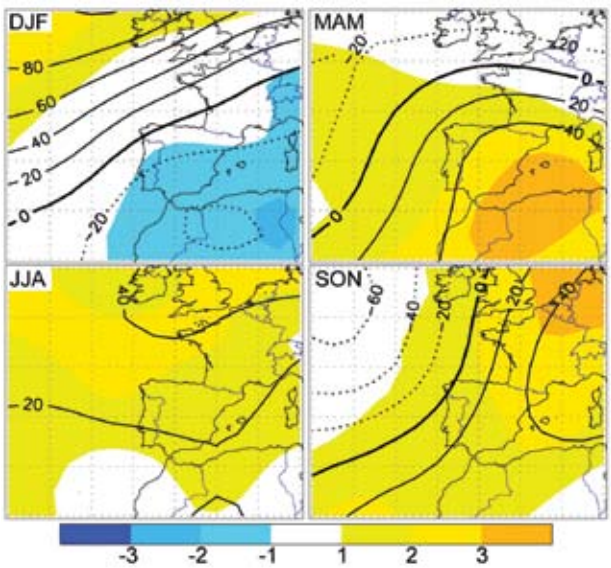

Fig. 6.38. Seasonal anomalies of 500-hPa geopotential height contours and corresponding 850-hPa temperature anomaly field (color, °C) compared to 1961–90 base period. [Source: NCAR–NCEP reanalyses.]

temperature anomalies in Switzerland varied between 1° and 1.7°C above average, placing 2006 as the fifth warmest year in the records since 1864. In most areas of Austria, temperature anomalies in 2006 ranged between 0.2° and 1.0°C above average. Poland and the Czech Republic also experienced above-average temperatures ranging between 1° and 2°C above the mean temperatures of the reference period (1961–90).

Temperatures in Germany, Poland, and the Czech Republic were significantly below the long-term average at the beginning of the year. In Germany, mean January temperatures were 2.1°C below the long-term mean. In Poland and the Czech Republic, temperatures were even lower and Warsaw reported an average temperature anomaly of –5.0°C for January. Temperatures in February also remained below average over the whole region. March was the coldest in Germany for 10 years (anomaly of –2.0°C).

The alpine region experienced below-average temperatures from January to March with anomalies ranging from –0.5° to –1.5°C. In some regions of Austria temperatures were between –2° and –3°C and temperatures down to –24°C were measured during the first 20 days of March in Tyrol, with the lowest value on 13 March. These lower temperatures are consistent with NAO's negative phase (Casty et al. 2005); the NAO had a reading of –0.82 over the December 2005 to March 2006 winter.

In April and May, temperature anomalies rose to slightly above average (up to +1.5°C). Temperatures in the summer months (JJA) showed an extreme contrast. August was well below average in all regions. July was dominated by an extended anticyclone over the Azores, which was stationary over Europe for a long time. This led to an extreme heat wave in central Europe and adjacent areas (Fig. 6.39). The average temperature in Germany was 21.8°C, the warmest in the 106-year record, with an anomaly of 4.9°C above the 1961–90 mean. Temperature anomalies in July in the Czech Republic were 4°–5°C above average. In Vienna, Austria, where observations started in 1775, a new July record for monthly mean temperature (23.9°C) was set. The warmest areas, with anomalies above 5°C, were found in the northern parts of the Alps. August was somewhat cooler than normal across the region.

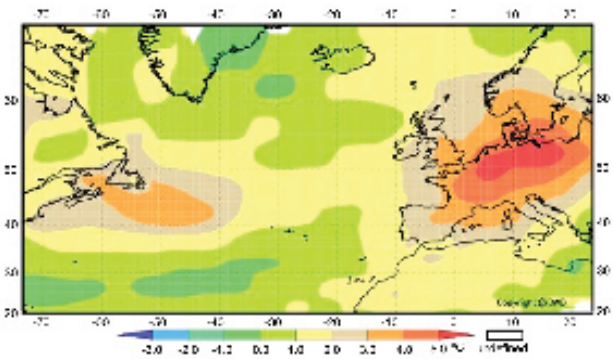

Fig. 6.39. Monthly average near-surface air temperature anomalies (°C; 1961–90 base) for July 2006. [Source: DWD via CLIMAT messages and ship data.]

Autumn was extraordinarily warm in central Europe and neighboring areas. It was by far the warmest autumn in central Europe since meteorological measurements began. Seasonal temperature averages in Germany were 3.2°C above the long-term mean. Remarkably, September average temperatures (16.8°C, +3.5°C anomaly) across the region were even higher than in August (15.4°C, –1.1°C anomaly). These extreme temperature anomalies are mostly explained by the anomalous southwesterly flow. In Germany, December was the warmest it has been for 32 years (3.4°C above normal). Northern Germany, the Czech Republic, and Poland experienced anomalously high temperatures exceeding the 90th percentile in places. The highest anomalies occurred in northeastern Poland (> 4°C).

(ii) Precipitation

Precipitation in central Europe in 2006 was close to average. Northern Germany and parts of Poland were drier than average while southern Germany and the Czech Republic experienced slightly above-average precipitation. Annual precipitation anomalies averaged over the entire area of Germany were 93% of normal. Austria experienced below-average precipitation (70%–90%) in the southern provinces, eastern Tyrol, Carinthia, and southern Styria, but totals were above average (110%–130%) in the north. In Switzerland, negative precipitation anomalies were restricted to southwestern regions and most parts of Switzerland experienced 110%–140% of their normal precipitation amount in March and April and the significantly wet months of May and August.

In winter, the region was drier than normal with 74% of the normal precipitation amount in Germany. January was particularly dry with only 39% of normal rainfall. Precipitation during the winter mostly fell as snow. February saw the heaviest snowfall in southern Germany for more than 10 years. Rainfall amounts in spring were significantly above average in many parts of central Europe. Germany received 130% of its normal rainfall. In April, melting of the large amounts of lying snow coupled with above-av-

erage precipitation resulted in one of the largest spring floods in the past 50 years in southern and eastern Germany. The Elbe River rose to record levels in parts of northern Germany, breaking the records set during the 2002 flood.

Summer precipitation was correlated with temperature; the warm June and the extraordinarily hot July were also remarkably dry (50% and 65% of the normal in Germany). In July, areas of the Czech Republic, eastern Germany, and the Bavarian forest received less than one-fifth of the normal average rainfall for the month. Prague (Karlov) reported only 12.5% of its normal precipitation. August was unusually wet. Autumn saw drier-than-normal conditions in Germany (80% of the normal rainfall), and some areas along the Danube River received only about 30% of the average. In southern and eastern Austria, anomalies ranged between 40% and 80%. Rainfall totals in September were significantly below average over large parts of Germany, Austria, Poland, and the Czech Republic.

(iii) Notable events

On the evening of 31 October–1 November, a severe storm occurred over northern Germany. Wind gusts of more than 150 km h^{-1} were registered over the northern German islands. On the island of Borkum, the water level reached that of the historical flooding event of 1962.

5) Western and northwestern Europe—A. Obregón, P. Bissolli, and J. J. Kennedy

(i) Temperature

Temperatures in northwestern Europe in 2006 were above average in all areas, with parts exceeding the 98th percentile of the 1961–90 distribution. The United Kingdom and the Netherlands, which have some of the longest weather records in the world, reaching back to 1659 and 1706, respectively, reported their warmest years in history. Annual average temperatures were 1.42°C above the 1961–90 average in the United Kingdom. In Ireland, it was the warmest year for at least nine years with annual mean air temperatures reaching up to 1°C above the normal. The mean annual temperature of 10.6°C in Dublin was the highest value since reliable measurements began there in 1855. The CET is the oldest continuous temperature dataset in the world (Parker and Horton 2005; Parker et al. 1992). The mean CET for 2006 was 1.35° ±0.09°C above the 1961–90 average and exceeded all values in the series going back to 1659.

Across Ireland and large parts of the United Kingdom, March was the only month with widespread below-average temperatures. The Low Countries and France experienced an unusually cold winter. Temperatures in spring were close to or slightly above average in the Netherlands and France, while summer temperatures were considerably above average in June and July. August was, by contrast, rather cool. July 2006 was the warmest month on record for the Netherlands and Belgium, where records began in 1830. The mean temperature for July was around 5°–7°C above the 30-year meteorological average. Temperature anomalies in July in France were above 4°C in most parts of the country, where it was the hottest July in the 57-year record and the second hottest month overall behind August 2003.

The warmest September in the CET series (16.8° ±0.2°C, +3.2°C anomaly) contributed to the warmest autumn (12.6° ±0.12°C). Indeed, in central England, autumn 2006 was nearly seven standard errors warmer than the next warmest autumns recorded in 1730 and 1731 (11.8°C). Autumn was also the warmest ever in the De Bilt (Netherlands) series, which started in 1706. The mean temperature of 13.6°C in De Bilt was exceptionally high even compared to the previous record temperature of 12.0°C. September was the warmest ever recorded in the Netherlands. France experienced temperatures above the 90th percentile in October and November. October 2006 was the second warmest month in France since records began in 1950 with an anomaly relative to 1971–2000 of +3.3°C.

(ii) Precipitation

Annual average precipitation was close to the long-term mean for the northwestern European countries. However, there was significant seasonal and regional variability. The United Kingdom as a whole registered 107% of normal annual rainfall (1961–90). With 112% of normal rainfall, Scotland was the wettest British region in 2006. In Ireland, annual rainfall totals were above normal over most of the country.

The United Kingdom had its driest winter since 1964. France, Belgium, and the Netherlands experienced their highest negative rainfall anomalies in January and June, with totals in large parts of the country below the 10th percentile. Spring precipitation was slightly above normal in most of the region, with the highest anomalies in Northern Ireland, Wales, and western parts of England. May was a significantly wet month in Belgium, Ireland, England, and Wales, where monthly precipitation totals were above the 90th percentile (w.r.t. 1979–2000) and the England and Wales region reported its wettest May

COUNTRY SPOTLIGHT: BOSNIA AND HERZEGOVINA—*Z. Majstorovic*

Bosnia and Herzegovina can be divided into three climate regions, which are covered by 13 professional meteorological stations. The lowest air temperature in 2006 was recorded in January: –24.7°C in Bjelasnica. The highest air temperatures was recorded in June in Mostar (41.2°C) Annual precipitation ranged from a high of 1218 mm in Bihac to a low of 716 mm in Zenica. The lowest monthly precipitation total was recorded in October: 11 mm in Jajce. The highest monthly precipitation total occurred at Ivan Sedlo (197 mm) in August. Overall, Bosnia and Herzegovina was 0.4°C warmer normal in 2006, while annual precipitation was slightly lower than normal.

Winter 2005/06 was slightly colder than average. December was near normal, January was significantly colder, and February was slightly colder than average. Precipitation was slightly higher than normal, mostly due to December rains, but the sums in January and February were below normal. Spring 2006 had near-normal temperatures: March was colder than normal, April was slightly warmer, and May was near normal. Precipitation was wetter than average, especially in March when the largest snow cover on record was reported in Bjelasnica: 345 cm. Average summer temperatures were near normal, but there were several periods of extremely high temperatures (especially in June), and some with temperatures below the LTM. Precipitation was slightly wetter than normal; some eastern locations reported their wettest August on record. Mean temperature during autumn (all 3 months; OND) were above normal, especially in October when the mean monthly temperature anomaly was +2°C. Fall precipitation was below normal.

for 23 years.

Summer rainfall in England and Wales was the lowest for a decade. Eastern Scotland, South Wales, and the southwest were particularly dry. Extremely dry conditions occurred in the Netherlands in June and July with very low rainfall amounts (only 39% of the normal in July), especially in the western part, which had less than 10 mm of rainfall. In contrast, August was extremely wet (above the 90th percentile) in the Netherlands, Belgium, and northern France. The Netherlands reported 297% of normal values in August.

Autumn was dry in the Low Countries and northern France, while conditions in Ireland, the United Kingdom, and western France were much wetter (150% of the normal in Ireland). The Netherlands received only 16% of the monthly average rainfall in September. Precipitation in France was lower only in its northern part, while wetter conditions occurred in the south of the country. Northern Ireland registered its second wettest September since 1985. Scotland experienced its wettest November (155% of the normal with some stations in the west receiving more than double the monthly average) and December in a rainfall series that began in 1914.

(iii) Notable events

At the end of September, the extratropical remnants of Hurricane Gordon brought strong winds and rain to the United Kingdom, particularly to Northern Ireland and Scotland. The remnants of Gordon produced widespread and sustained rainfall across Northern Ireland and Scotland, with winds gusting to 130 km h^{-1} in Northern Ireland. The southwest of England was also affected by high winds.

6) Baltic States and eastern Europe—A. Obregón, P. Bissolli, and J. J. Kennedy

(i) Temperature

In 2006, the region experienced above-average temperatures nearly everywhere, with anomalies increasing with latitude. The highest positive anomalies were observed in the Baltic States (e.g., Lithuania 0.9°–1.7°C). Temperature anomalies in eastern Europe were mainly between 0.5° and 1.0°C.

The year started with unusually low temperatures in January across the whole region, except northern parts of Estonia. Temperature anomalies during the first month were lowest in Belarus and Ukraine. The Baltic States were affected by the cold wave and experienced similarly low temperatures. In Serbia, a new record-low temperature of –39.0°C was measured in Karajukica Bunari on 26 January. February and March were also cold throughout most of the region.

The rest of the year saw mostly above-average temperatures throughout the region. The heat wave in July affected the western part of eastern Europe. Serbia experienced a remarkable heat wave between 20 and 29 July with temperatures of 5°C above the long-term mean. August showed a dipole pattern in temperature anomalies. The Baltic States and eastern regions of Belarus and Ukraine experienced high temperatures, exceeding the 90th percentile, while temperatures in Hungary, Slovenia, western Slovakia, parts of Croatia, Serbia, and Bosnia and Herzegovina were below the long-term mean. Autumn temperatures were generally well above average, especially in the Baltic States, Slovakia, and Hungary. The year ended with extremely high mean temperatures.

Temperatures in December mostly exceeded the 90th percentile. The capitals of Lithuania and Estonia reported mean temperature anomalies around +7°C. The influence of the Siberian air masses was significantly reduced by cyclones from the North Atlantic region.

(ii) Precipitation

In 2006, wide areas of eastern Europe experienced normal or above-average precipitation, while the Baltic States were mostly drier than normal. Precipitation in Lithuania was near normal due to an extremely wet August; Vilnius received more than 180% of its August average. The wettest regions were generally found in eastern Europe, with highest rainfall anomalies in Bulgaria.

Winter 2005/06 was drier than average in the Baltic States and wetter than average in eastern Europe. Spring precipitation totals were higher than usual in most areas, with the exception of the Baltic States. The distribution of summer rainfall across the whole region was similar to that seen in the spring with negative anomalies in the Baltic States and positive anomalies in eastern Europe. During the last months of the year, drier-than-normal conditions were to be found in Croatia and Bosnia and Herzegovina.

(iii) Notable events

An extraordinarily swift thaw in April produced extensive flooding along the Danube, which reached its highest level in more than a century. Areas in Hungary, Serbia, Romania, and Bulgaria were most affected. In Budapest, the water level of the Danube exceeded the record set in 2002. Romania was affected by several extreme weather events during the summer: a deadly mudslide in northern Romania in June and flooding in July within the same region.

7) Southeastern Europe—A. Obregón, P. Bissolli, and J. J. Kennedy

(i) Temperature

Temperatures in southern Europe were above average in 2006 through much of the region. Greece and the European part of Turkey experienced slightly above average temperatures. In the western regions of southern Europe, temperature anomalies were considerably higher. Italy had annual anomalies on the order of +1°C in the northern and central regions and about +0.5°C in the south.

In early 2006, Greece, Turkey and southern regions of Italy were also unusually cold. The monthly average maximum temperature in Athens was 2.1°C below the climatological norm. Temperatures in the European part of Turkey were below the 10th percentile. However, some areas on the Italian islands (Sicily and Sardinia) were also warm in the spring (anomalies up to 4°C), exceeding the 90th percentile.

Summer temperatures were generally above average. In Italy, June was characterized by warming in the north and in some points in the south (anomalies up to 3°–4°C). In July, most of Italy experienced temperatures above the 90th percentile. Monthly average maximum temperatures in the northeast of Italy reached new records in some regions. Temperatures in southern parts of Greece were above the 90th percentile in August, while regions in northern Italy were colder than the 10th percentile. Southern Italy, particularly Sicily, experienced unusually high temperatures in August. In Messina, an historical high temperature of 41.8°C was recorded. In Bologna, it was the second hottest autumn since 1948. December was colder than normal over Greece. Temperatures in large parts of Italy were above the 90th percentile during this month.

(ii) Precipitation

Most parts of northern Italy experienced drier-than-normal conditions, while central and southern Italy, Greece, and Turkey received positive rainfall anomalies. In the Po Valley in northern Italy, the low precipitation amounts caused drought conditions with reduced water availability. Spring was generally drier than average in Italy and Greece, due mainly to an unusually dry May. Summer conditions were generally wetter than normal in southern Italy and Greece, while northern Italy remained dry, especially in June. During this month, most of northern Italy experienced precipitation below the 10th percentile (1979–2000 base period).

Lower-than-average precipitation was also observed in Italy as a whole during autumn. Greece was significantly wet in September (rainfall above the 90th percentile), but precipitation was well below average in November (below the 10th percentile) in most regions. Rainfall on the Greek Aegean island of Samos was 920% of the average October value. December was dry across most of southeastern Europe, especially in southern Greece, although southern Italy and Sicily were very wet.

8) Middle East—A. Obregón, P. Bissolli, and J. J. Kennedy

(i) Temperature

Annual average temperatures were above average over nearly the whole region. The anomalies were

mostly between 0° and +1°C and partly above +1°C in the eastern parts (Georgia, Armenia, Azerbaijan, and western Kazakhstan). The cold spell that dominated Europe in January also affected the Caucasian countries and western Kazakhstan, where temperatures were lower than the 10th percentile with anomalies between –6° and –10°C. In February, warmer air from the southeast extended into the region and temperatures exceeded the long-term average during most of the spring season. The summer, too, was generally above average, with high anomalies in June and August, while July was mostly near average. A heat wave occurred in Cyprus between 19 August and 28 August, with maximum and minimum temperature anomalies of 2°–5°C above normal. The autumn was mostly warmer than normal. Significant anomalies occurred in October when eastern parts of the region were 3°C above average.

(ii) Precipitation

Precipitation totals from December 2005 to November 2006 were mainly near normal. Cyprus and Azerbaijan were the exceptions in that they were very dry, with some areas receiving less than 50% of the annual precipitation average. The annual average for Cyprus was 77% of the normal, although October and November were particularly wet.

h. Oceania

1) Australia—A. Watkins and B. Trewin

Despite only weak-to-moderate El Niño conditions in the Pacific, Australia, as in 2002, experienced above-normal pressures during the year, which suppressed convection and kept cold fronts south of the continent. As a result, significant dry conditions were experienced over much of the country by the second half of 2006. For many of these areas the drought of 2006 added to significant longer-term rainfall deficiencies, with large regions having experienced little recovery from the droughts of 1997/98 and 2002/03, resulting in severe hydrological drought throughout much of eastern and southwestern Australia.

However, a vigorous wet season across northern Australia, as well as the inland penetration of tropical cyclones into remote areas of western Australia early

COUNTRY SPOTLIGHT: ARMENIA—A. Hovsepyan

The year 2006 was 1.2°C warmer than normal all over Armenia (Fig. 6.40). It was the seventh warmest year in Armenia since 1929. Annual precipitation totals were close to the 1961–90 normal. The northeastern and southern parts were very dry, while central parts received above-average precipitation. Winter 2005–06 was rather warm, with seasonal temperatures 1°C above the 1961–90 mean. The summer was the hottest in 70 years; seasonal temperatures exceeded the 1961–90 mean by 2.7°C. Mean summer precipitation was only 60% of normal.

January was colder than normal by 1.5°C all over Armenia. Precipitation exceeded the normal by about 40%. Temperatures in February were higher than normal by 1°–1.5°C, except in the Ararat valley, where negative anomalies reached –1.5°C. March was very warm (anomalies of 2°–3°C) and dry (60%–70% of normal precipitation) over the country. April was warm and rainy across Armenia. Precipitation totals exceeded the normal by 60%–70%. Climatologically, April–May is the wettest period of the year in Armenia, but in 2006, some regions reported no rain in May. Severe drought developed across the country in June. Mean monthly temperature was above normal by 4°–4.5°C. August was very hot and dry, as monthly temperature anomalies reached 3.5°–4°C. During a heat wave (6–15 August) maximum temperatures reached up to 42°C.

In September, the monthly mean temperature was 2°–4°C higher than normal. October was quite warm (2.7°C higher than normal) and wet (precipitation totals exceeded the normal by 150%–250%). December was very cold. The monthly mean temperature was 2.2°C below normal. Precipitation was generally about 60% of normal.

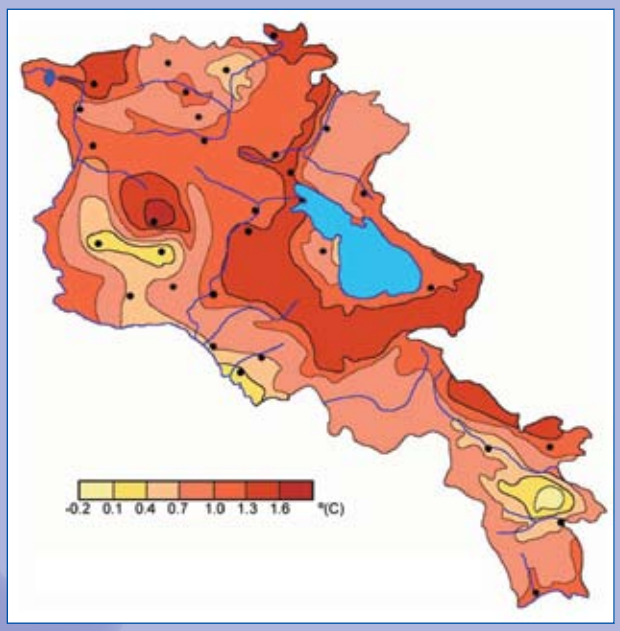

Fig. 6.40. Annual average air temperature (°C) anomalies for Armenia.

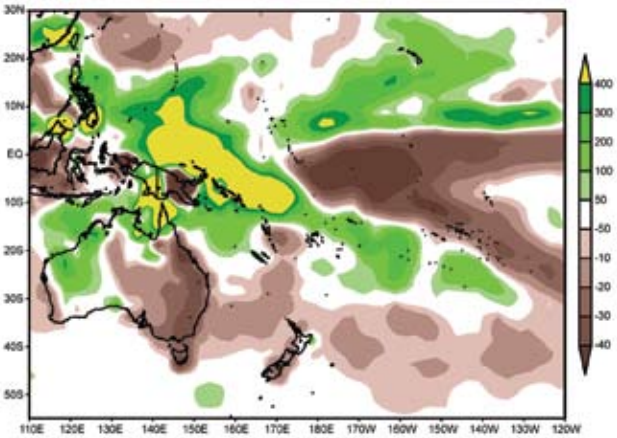

Fig. 6.41. 2006 annual precipitation anomalies (mm, 1979–2000 base) for Oceania from CAMS-OPI.

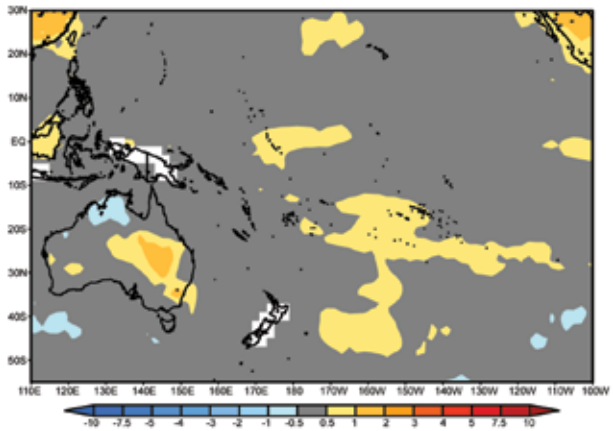

Fig. 6.42. 2006 annual temperature anomalies (°C, 1971–2000 base) for Oceania from CAMS-OPI.

in the year, largely offset the acute dry in the country's main population and agricultural areas of the south and east (Fig. 6.41). The wetter-than-average conditions in the north and northwest of the continent earlier in the year reduced daytime maximum temperatures in these areas, while high pressures brought clear skies and cold nights to the southeast and a cool winter in the Tropics. Overall, much of eastern Australia had above-average temperatures in 2006, while a small patch in the north was cooler than average (Fig. 6.42).

For eastern and southwestern Australia, the big drought of 2006 was exacerbated in the latter months of the year by very warm conditions. Spring 2006 was Australia's warmest since seasonal records commenced in 1950. The driest and warmest 5-year period on record in the major Australian cropping zones, in addition to a general failure of rainfall during the 2006 April–October crop and pasture growing season, contributed to extremely large downturns in agricultural production.

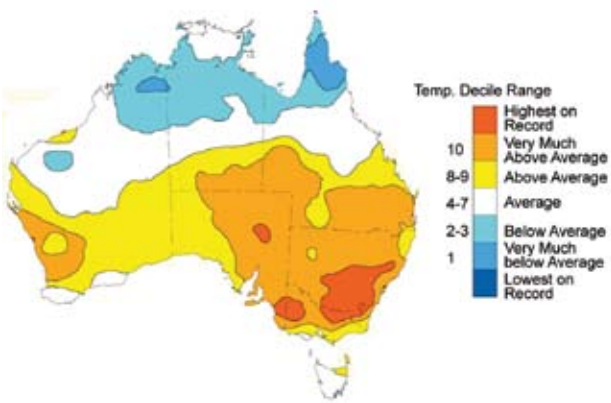

Fig. 6.43. Australian maximum temperature deciles for 2006 (1950–2006 base).

(i) Temperature

Maximum temperatures for 2006 were mostly above normal for areas south of the Tropics, resulting in 33% of the continent experiencing daytime temperatures in the top decile (Fig. 6.43). New South Wales, Victoria, and the Murray Darling Basin (Australia's "food basket") all recorded their second warmest annual maximum temperatures (behind 2002) on record[7] (1.55°, 0.97°, and 1.54°C above average, respectively). Overall, Australia's maximum temperatures were the ninth warmest on record, with an anomaly of +0.60°C.

In some contrast, minimum temperatures for the year were cooler than normal in the southeast, as well as in the top end of the Northern Territory and the Kimberly region of western Australia. However, inland regions were generally warm at night despite the reduced cloud cover, with temperatures ~0.5°C above normal. South Australia and Queensland both had their 10th warmest nighttime temperatures on record (+0.65° and +0.56°C above the 1961–90 average, respectively), and with 40% and 36% of the states in decile 10. The Australian minimum temperature anomaly for 2006 was +0.34°C, the 17th warmest.

[7] High-quality *annual* Australia-wide temperature anomalies have been calculated for all years since 1900 (Della-Marta et al. 2004), while high-quality *monthly* anomalies are available from 1950. High-quality nationwide rainfall measurements commenced in 1900 (Lavery et al. 1997). Anomalies are calculated with respect to the 1961–90 average, in accordance with World Meteorological Organization guidelines.

Australia's mean temperature for the year was 0.47°C above the 1961–90 mean, making it the 11th warmest year on record.

(ii) Precipitation

With only January, April, and July bringing widespread near- or above-average rainfall to Australia, 2006 proved to be an extremely dry year for most regions south of the Tropics (Fig. 6.44). Aside from Darwin, Australia's northern-most major city, all of the densely populated regions of Australia, as well as the vast majority of Australian agricultural areas, experienced significantly below normal rainfall for the year. Victoria, New South Wales, and Tasmania had 96%, 45%, and 72% of their state in decile 1, giving them their third (366 mm), ninth (349 mm), and third (877 mm) driest years, respectively. For southeastern Australia, this was the second-driest year (367 mm) after 1982 (355 mm), while in the southwest of the continent, it was sixth driest (476 mm). It was the driest year on record for the cities of Perth and Hobart, and the second driest for Adelaide. The agriculturally vital Murray Darling Basin experienced its third-driest year on record, after 1902 and 1944. When added to the long-term dry, the resulting inflows to Australia's second-longest river, the Murray, were lower than that of the previously lowest inflows, which occurred in the Federation drought of 1902. Rainfall anomalies were particularly extreme in the highlands of eastern Victoria, southern New South Wales, and northern Tasmania. Stations such as Burnie in northwestern Tasmania (408 mm, previous record 670) and Harrietville in northeastern Victoria (504 mm, previous record 710) were more than 200 mm below their driest recorded year.

The dry conditions blanketing the major population and agricultural regions added to long-term rainfall deficiencies. By the end of 2006, New South Wales had experienced dry conditions for over five years; southeast Queensland, seven years; Victoria, northern Tasmania, and eastern south Australia, 10 years; and in southwest western Australia, some 30 years.

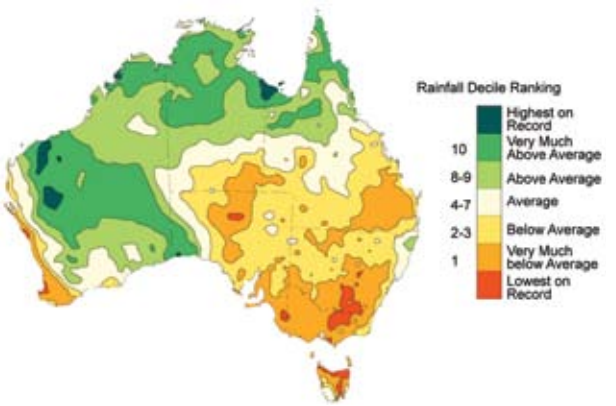

Fig. 6.44. Australian rainfall deciles for 2006 (1900–2006 base).

In contrast, the wet season (October 2005–April 2006) over northern Australia was the fifth wettest since high-quality rainfall records commenced in 1900, with an average of 674 mm falling over the period. This was despite an initially weak and late start to the Australian monsoon. At Darwin, the monsoon onset did not occur until around 13 January, about two weeks later than the usual timing of 28–29 December (Drosdowsky 1996). Overall, Australia recorded 490 mm (long-term average 472 mm) for the year, making it the 32d wettest year of the 107 years of record. However, such a relatively wet year would be contrary to the experience of most Australians, with the vast majority living within the 39% of the continent, which received rainfall in the lowest three deciles.

(iii) Notable events

Tropical Cyclone Larry (see section 4) was category 5 shortly before it crossed the coast as category 4, the most intense system at landfall in Queensland since 1918. Similarly, during the passage of Tropical Cyclone Monica along the Northern Territory coast, it became a category 5 system and the strongest ever observed in the Northern Territory region.

A major unseasonal cold outbreak affected southeastern Australia from 15 to 17 November (late spring). Snow fell near sea level in southern Tasmania, above 400 m in central Victoria, through large parts of the NSW tablelands, including the nation's capital Canberra, and as far north as Queensland. Numerous record low maximum temperatures were set. A Queensland State November record of 0.0°C was set at Stanthorpe and Applethorpe, and Sydney (8.3°C) had its coldest November night since 1905.

Persistent extreme heat affected much of eastern inland Australia from late December 2005 through early March 2006, with many records being set for average temperatures or consecutive days above thresholds. At Windorah (Queensland), there were 55 consecutive days above 37.8°C (100°F) from 30 December to 22 February, and 63 consecutive days above 35°C ending on 2 March. Birdsville's January mean monthly minimum of 30.0°C was the first time an Australian station had recorded a monthly average minimum of 30°C or above.

A severe early spring heat wave occurred in southeastern Australia in early October, with many locations

setting early season records. On 12 October Adelaide reached 37.9°C, Melbourne 36.6°C, and Hobart 33.1°C, all early season records. This was Melbourne's earliest postwinter 35°C+ day on record (records commence 1856), which followed its earliest postwinter 30°C+ day which had occurred only the month before (30.1°C on 19 September 2006). October was the hottest on record for New South Wales and Victoria.

Persistent extreme heat affected much of central and inland eastern Australia during the second half of November. November record highs were set over much of southwestern Queensland, and Birdsville reached 48.5°C on 30 November, which was 0.2°C below the Australian November record set there in 1990. Many locations set records for extended November hot spells, including Canberra (11 days above 30°C) and Alice Springs (12 days above 37.8°C, or 100°F).

Numerous major bushfires occurred in Victoria during January 2006. There were also significant fires during this period in Tasmania. With dry and hot conditions, major fires in South Australia, New South Wales, Victoria, and Tasmania occurred far earlier than in previous years. Lightning strikes on 1 December sparked an immense blaze in Victoria's Gippsland and northeast regions. The fire lasted over two months and burned approximately 1.1 million ha.

With clear skies and very low soil moisture, a number of major frost episodes occurred in the southern half of Australia during late May and June. One extreme event occurred on 30 May, when state records for the month were set for Queensland (–6.8°C at Stanthorpe) and Tasmania (–10.5°C at Liawenee). In western Australia, a state record for June (–6.0°C) was set at Collie East on 17 June, the same day the city of Perth recorded its first subzero minimum (–0.7°C). A succession of frost events also caused damage in southeastern Australia during late September and October. The most damaging event occurred on 25 September, when widespread subzero temperatures in northern Victoria led to major losses in the Goulburn Valley fruit crop (estimated at $70 million Australian). A new Australian record low temperature for October was set on the 29th when Charlotte Pass (New South Wales) reached –12.0°C.

2) New Zealand—J. Salinger

(i) General conditions

Erratic and sometimes extreme, New Zealand's climate for 2006 featured one of the severest winter snowstorms in decades, a very windy spring, and a rather cool start to summer in December 2006. The national average temperature of 12.4°C in 2006 was 0.2°C below the 1971–2000 normal. Thus, 2006 ended up very close to the 1971–2000 normal, as a compromise between very warm months (April and September) and very cold months (March, June, December). April was the warmest and June the coldest in the last 30 years, September was the third warmest on record, and December one of the coldest in the last 60 years. Temperatures were above normal in the northeast of both islands, but below normal in inland areas of the South Island. Well-below-normal rainfall occurred throughout parts of central Otago (southeast of South Island), with totals less than 75% of normal, as well as in Awatere Valley in Marlborough. Rainfall was well above normal in the southern North Island and Christchurch areas, with totals at least 120% of normal. The year was dominated by more anticyclones in the Australian Bight/Tasmania area, with stronger westerlies in the Southern Oceans, giving windier southwesterlies over New Zealand.

(ii) Notable events

The highest recorded extreme temperature of the year occurred during a heat wave in central Otago toward the end of January. Alexandra recorded maximum temperatures of 36°C for three consecutive days from 27–29 January (unheard of in their historical record, commencing in 1930).

The lowest air temperature for the year was –14.0°C recorded at both Tara Hills, Omarama, on 14 June, and Fairlie on 28 June. The minimum air temperatures were –10°C or lower in parts of inland south Canterbury and/or north Otago, on nine days between 14 and 29 June.

The highest recorded wind gust for the year was 180 km h^{-1} and was recorded from the northwest, at Southwest Cape (Stewart Island) on 2 September, which is a new record for a wind gust at that site. Mean wind speeds reached 128 km h^{-1}.

The driest rainfall recording locations were Alexandra in central Otago with 266 mm of rain for the year, followed by Clyde with 286 mm.

Of the regularly reporting gauges, the Cropp River gauge in Westland, inland in the headwaters of the Hokitika River, recorded the highest rainfall with a 2006 annual total of 11,370 mm.

Nelson was the sunniest center in 2006, recording 2580 hours, followed by Blenheim with 2528 hours, and Tauranga with 2507 hours.

Invercargill recorded its sunniest year on record with 1853 hours, and Kaitai, Tauranga, and Dunedin their second sunniest.

The year began with significant soil moisture deficits in the north and east of the North Island and

eastern South Island, which persisted in these regions until March. March was cold, and an ex–tropical cyclone produced high rainfall in the north of the North Island. Flood-producing rainfall events occurred in north and east Otago and in the Hauraki–Coromandel region during April. As a result, the month's rainfall was very high in these regions. Rainfall in north and east Otago totalled 300%–400% of normal, and totals in the Hauraki–Coromandel region were at least 200% of normal. It was the eighth warmest April on record. May produced well-above-average rainfall in the north of the North Island, and east of the South Island, with low rainfall in parts of the south of the South Island. Two severe winter snowstorms accompanied by bitterly cold conditions, and later heavy frost, contributed to a particularly cold June. Temperatures were 2°C below average in some regions. It was much sunnier than normal in all western and southern regions, with record high June totals in the north of the North Island, and coastal Otago. In contrast, July was warmer than June, going against the usual trend. It was very wet in the south and west of the North Island, with twice the normal rainfall in Wairarapa with flooding. July was rather dry in other areas with rainfall totals a mere 25%–50% or less of normal in the north of the North Island and Otago. High rainfall continued in August in the south and west of the North Island, but it was dry in much of the South Island, and extremely sunny in the south. September was a month of climate extremes with record low rainfall and high mean temperatures at many locations. Rainfall was low throughout much of New Zealand, especially in the east, with some locations recording 10% or less of normal rainfall. In some areas temperatures were 2°C above average, with windy conditions in the south. It was windier than usual over most of the South Island and southern half of the North Island in October, with several locations in Marlborough and Otago recording their windiest October in over a decade. November produced stormy westerlies over the South Island: it was particularly warm in the east of the North Island, yet cold in the southwest of the South Island. Significant soil moisture deficits existed in Northland and central Marlborough by the end of the year. December ended the year on a cool note, with one of the coldest Decembers in the last 60 years, as more frequent southerlies brought temperatures 2°C below average.

Notable climate features in various parts of the country included numerous heavy rainfall events of which 18 produced floods. Snowfall events occurred on 11 occasions, mainly in high country areas from midautumn to late winter, with ski areas having an extended season. Other climate extremes included a summer heat wave, seven tornado-like incidents, three severe hailstorms, and many damaging windstorms. The most significant extreme event of the year was the winter snowfall event over the night of 11/12 June in Canterbury, especially in the south, with snow settling to sea level. The worst flooding events during 2006 were those of 25–26 April in Otago and 4–6 July in Wairarapa. In the Otago flood, rivers ran extremely high, and much of the Taieri Plains including Mosgiel were flooded, with some evacuations. Floodwaters also affected the towns of Oamaru and Waitati. The Wairarapa flood occurred during a 3-day period of high rainfall, also affecting Wanganui and Wellington.

3) Southwest Pacific—J. Salinger

This year saw a change from a La Niña to an El Niño climate pattern in the Pacific. The first quarter of the year was dominated by weak La Niña–like (cold episode) characteristics, followed by a neutral period. Weak-to-moderate El Niño conditions in the tropical Pacific were in place by September, which peaked in December. A higher frequency of surface equatorial westerlies occurred near the date line from August through November (the highest persistence since the 2002 El Niño event when surface westerlies were much stronger). Trade winds generally were near normal in strength at other times of the year. The SPCZ was farther south than usual from January through May (typical for La Niña), but was near its normal location throughout much of the remainder of the year. Below-average equatorial SSTs occurred around western and eastern Kiribati with the cold episode (–1°C anomalies), returning to normal by April. Positive SST anomalies (+0.5°C) became apparent near the date line in the equatorial Pacific in June. These warmed to a constant +1.5°C above average in the seas around western and eastern Kiribati from August/September onward. Negative SST anomalies occurred around New Caledonia from August through December, more than 1°C below average in October. These features were also consistent with El Niño development. From January through June, OLR anomalies showed enhanced convection over the Solomon Islands and Papua New Guinea. Suppressed convection occurred over western and eastern Kiribati from January through May, with a reversal to enhanced convection from August through December. For much of the year, mean SLP was below average east of the date line. However, positive anomalies prevailed in the western Pacific over Australia and the Tasman Sea from May onward.

For 2006 as a whole, above-average SSTs occurred

throughout much of the tropical southwest Pacific. These were at least +0.7°C above average throughout central and southern French Polynesia, extending to the southern Cook Islands and Pitcairn Island. Some locations experienced above-average SSTs for 11 months of the year. SSTs were at least +0.5°C above average in many other tropical island nations, especially those near and east of the date line. SSTs were near average in the region between Papua New Guinea and New Zealand, including New Caledonia. Southwest Pacific island surface air temperature anomalies for 2006 were consistent with the SST anomalies throughout the region. It was an extremely warm year in Fua'amotu, Tonga, where the mean temperature of 24.6°C was 0.8°C above the historical average and was highest since measurements commenced in 1980. Tahiti Faa'a, in French Polynesia was also much warmer than usual, with a mean temperature of 26.9°C (0.7°C above the 1971–2000 normal).

OLR anomalies (Fig. 6.45) showed a region of enhanced convection over Papua New Guinea and the Caroline Islands to the north, extending southeast to the Solomon Islands and northern part of Vanuatu. Another area of enhanced convection, although not as strong, occurred over Niue and the southern Cook Islands. Convection was suppressed in a horseshoe-like pattern in 2006 over eastern Kiribati and parts of western Kiribati, extending to the northern Cook Islands and southeast over the Tuamotu Islands of French Polynesia and to Pitcairn Island.

The year's rainfall anomalies were similar to those of the OLR, with above-average (at least 110% of normal) rainfall over much of the Solomon Islands, northern Vanuatu, Niue, and the Southern Cook Islands, as well as parts of central and southern French Polynesia. Rainfall was below average (less than 90% of normal) in the North Tasman and over New Caledonia, as well as parts of eastern Kiribati and the northern Cook Islands. One location, Rotuma Island, Fiji, recorded an extremely high 2006 rainfall of 4378 mm (128% of normal). Two locations recorded well-below-average annual totals. These were Noumea, New Caledonia, with 735 mm (75% of normal), and Raoul Island, New Zealand, with 948 mm (61% of normal).

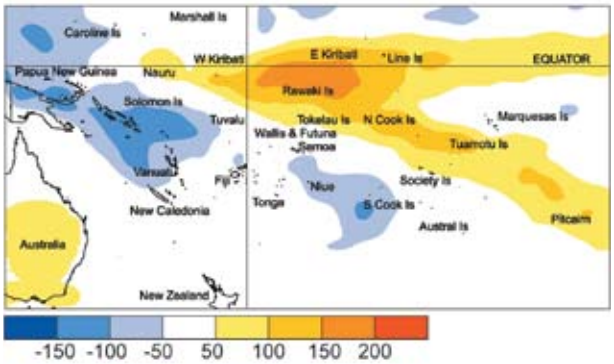

Fig. 6.45. Annual South Pacific OLR anomalies (W m^{-2}). High radiation levels (yellow or orange) are typically associated with clearer skies and lower rainfall, while low values (blue) often indicate cloudy conditions and more rain for the region.