December over northern South America, with the exception of Venezuela. During the last quarter of 2016, Venezuela had significant positive precipitation anomalies in the central region (173%–216% of average), central Llanos (up to 234% of average), western Llanos (166%–186% of average), and the eastern region (162%–225% of average).

2) Central South America—J. A. Marengo, J. C. Espinoza, L. M. Alves, J. Ronchail, and J. Baez

The central South America region includes Brazil, Peru, Paraguay, and Bolivia. The 2016 climate conditions were characterized by extreme high temperatures and below-average precipitation in the Amazon and Andean regions, while above-average precipitation was observed in northern Peru and northeastern Paraguay.

(i) Temperature

Temperatures across most of central South America were between 2°C and 3°C above normal during 2016, with the exception of May and June when cooler-than-average temperatures were observed at the beginning of May and in mid-June. During January–April and July–December, temperatures were 1.5°–3°C above average in Amazonia and eastern Brazil.

(ii) Precipitation

With the exception of January 2016, the dry conditions observed in 2015 persisted in eastern Brazil and in Bolivia (see Sidebar 7.2). The Amazon experienced drought conditions that were likely influenced by the strong El Niño episode. Between January and July, the dry conditions contributed to an increase in the number of wildfires, which were more than 740% of the 1999–2016 average in the state of Amazonas. The drought conditions that started in 2010 in northeastern Brazil persisted in 2016. Figure 7.14 shows the evolution of the water deficit across the semiarid region of northeastern Brazil from the beginning of the drought though 2016 (Marengo et al. 2017). Southern Bahia and the northern parts of the state of Minas Gerais, over the San Francisco River basin, were the most affected.

In 2016, above-normal precipitation was observed in northeastern Paraguay, particularly notable during December, with rainfall totals 200% of average. The heavy precipitation raised Paraguay's Asunción River discharge to 4500 $m^3 s^{-1}$ on 21 December. The mean discharge for December is 2000 $m^3 s^{-1}$.

(iii) Notable events and impacts

Several cold air outbreaks impacted the region in 2016. During 27–30 April, most of Paraguay was affected by its most intense cold wave in 57 years, with minimum temperatures dropping to 4.5°C in Pedro Juan Caballero and Mariscal Estigarribia, where average temperatures are 17.4°C and 18.5°C, respectively. The same cold front affected Urupema, Brazil, on 28 April, where minimum temperatures were as low as −3.2°C. Due to a cold air intrusion on 2 May, São Paulo recorded a minimum temperature of 10.0°C, the lowest temperature observed during May in 45 years (May average: 13.8°C). During the first half of

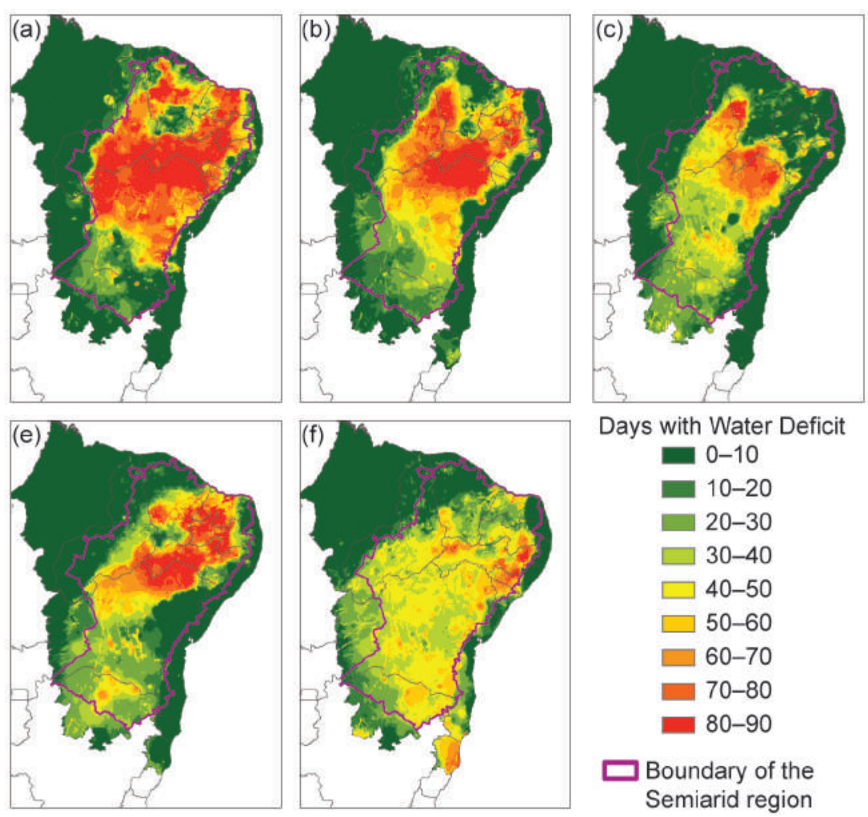

Fig. 7.14. Maps depicting water deficiency (in days) for Northeast Brazil during its hydrologic year (Oct–Sep): (a) 2011/12, (b) 2012/13, (c) 2013/14, (d) 2014/15, and (e) 2015/16. Thin purple line represents the boundary of the semiarid region. [Source: Marengo et al. (2017).]

June, a cold wave brought cooler-than-average conditions (Fig. 7.15) from southern Brazil to western Amazonia. Four people died in the city of São Paulo due to the cold on 13 June, where minimum temperatures were as low as 3.5°C (average is 12.4°C). On that same day, minimum temperatures were as low as −8.5 C at Urupema, while Rio de Janeiro's minimum temperature was 8.6°C (average is 18.7°C)—the lowest daily June minimum temperature in the last 14 years.

Severe weather, including heavy rains, floods, flash floods, and landslides, severely affected central South America for most of the year (with the exception of December). In central Brazil, heavy rain in January affected more than 67 000 people throughout the state of Mato Grosso do Sul, with 28 municipalities declaring a state of emergency and nearly 1000 people isolated in the Taquarussu district. Recife recorded

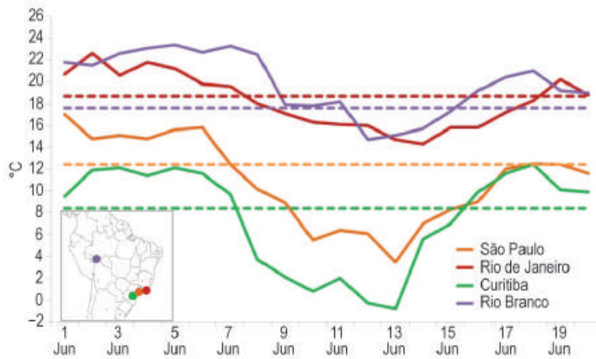

Fig. 7.15. Solid lines represent the mean temperatures (°C) in São Paulo, Rio de Janeiro, Curitiba, and Rio Branco during 1–20 Jun 2016. Dashed lines represent the respective 1981–2010 average (Source: INMET.) Colored dots in the inset map show the locations of the meteorological stations.

SIDEBAR 7.2: DROUGHT IN BOLIVIA: THE WORST IN THE LAST 25 YEARS—J. A. MARENGO, J. C. ESPINOZA, L. M. ALVES and J. RONCHAIL

Rainfall in the central Andes was deficient in 2016. During the January–April growing season (Fig. SB7.3a), rainfall totals were below average in the central and southern Andes of Bolivia and in the southern Chaco region. Oruro received 66.7% of its average precipitation (average: 240 mm) and Cochabamba just 62.1% of its average precipitation (average: 290 mm; Fig. SB7.4). These were the lowest values since the strong 1982/83 El Niño event. Scarce rainfall was also observed in the lowlands, where totals were 20% below average in Trinidad (Beni).

Drought persisted after the dry austral winter season (June–August) and at the end of the year rainfall totals for November–December were about 150 mm month^{-1} below normal. Total precipitation in La Paz and the Altiplano region (Fig. SB7.3b) during September–December 2016 was 25% below normal. Intense drought conditions affected the center and southern parts of the country and the region of Santa Cruz, in the southern lowlands, with deficits surpassing 30% in the Andean regions, which were already affected during the first part of the year (Fig. SB7.3a). The hydrology of the Peruvian side of Lake Titicaca showed low river discharge from October 2016, with the Ramis and Ilave Rivers recording discharge levels of just 3.85 m^3 s^{-1} and 11.6 m^3 s^{-1} compared to their respective climatologies of 17.9 m^3 s^{-1} and 51 m^3 s^{-1}. The water level of Lake Titicaca at Huatajata station dropped to 3807.78 m in December 2016, just shy of tying its lowest level set in September 1996 (3807.39 m). The Desaguadero River (the main outlet of the Lake Titicaca) discharge dropped as well. In the lowlands, a much longer-than-usual flood recession period was observed, especially in the Mamoré River, located downstream from the

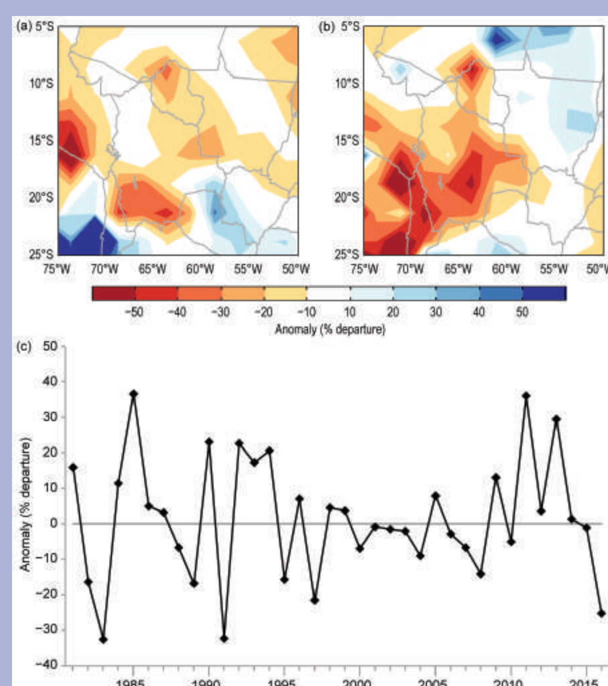

Fig. SB7.3. Precipitation anomaly (%; 1981–2010 base period) maps for Bolivia, derived from the CMAP dataset for 2016: (a) Jan–Apr, and (b) Sep–Dec. (c) Sep–Dec precipitation anomalies (%) near La Paz, Bolivia, during 1982–2016. (Source: Rainfall data is from CMAP, produced by NCEP.)

188 mm of rain in just 6 hours on 30 April—57% of the mean climatology for the month (328 mm). The copious rain prompted flash floods and landslides in several locations across the city.

Due to a South Atlantic convergence zone episode on 16 January, above-average rain (+150 mm) was observed in states across northeastern, central, and southeastern Brazil and eastern Bolivia, as well as in western Paraguay and northwestern Peru, causing floods and river overflow. In seven municipalities in the Bolivian department of La Paz, a state of emergency was declared due to intense rainfall that led to overflowing rivers during the first half of the year.

Torrential rainfall, which began in November 2015, continued during January, triggering the overflow of Paraguay's Asunción and Alberdi River levels (7.88 m in Asunción on 1 January and 9.81 m. in Alberdi on 6 January) and displacing more than 65 000 people in Asunción and leading the government to recommend evacuation of the Alberdi city. This was the fourth largest extreme flooding event since 1905, and according to the Meteorological Service of Paraguay, it was related to the 2015/16 El Niño event. This was also an out-of-season event since river levels typically reach their maximum at the end of May or in June–July.

In the Andean region, extreme drought was reported during 2016, leading the Peruvian government Ministry of Agriculture to declare a state of emergency for 17 regions during November and December.

The extreme dry conditions observed in northeastern Brazil contributed to a water crisis where the reservoirs of the San Francisco River were at less than 10% of capacity, leaving small farmers and the driest regions discussed above. At the Guayaramerin station very low levels, ~2 m, were observed from July to November compared to the usual September–October period. The severe dry conditions caused water supply issues for people, cattle, and agriculture in the region.

In November, Bolivia declared a national emergency, with drought affecting five of its nine departments. It was also declared due to the impact of dry conditions stemming from El Niño. Previous droughts were observed during past El Niño years in 1983, 1991, and 1997 (Fig. SB7.3c).

Bolivia's Civil Defense estimated that the drought conditions affected 162 000 families and threatened 607 000 hectares of agricultural land in the Andes and in the Amazonian region of Santa Cruz. About 360 000 head of cattle were lost due to the lack of water and fodder. The association of producers of oleaginous seeds and wheat estimated that in 2016 the production of soy in the lowlands of Bolivia decreased by 20%. The UN Food and Agriculture Organization estimated that the losses in Bolivia were as high as $485 million U.S. dollars (14% of the agricultural gross domestic product in 2015). Drought prompted protests in major cities and conflicts between miners and farmers about the use of aquifers. Water rationing was established for the first time ever in La Paz, affecting one-third of the population and probably more in fast-growing El Alto, the poorest city of Bolivia. The three main reservoirs that provide the city's water were almost dry by the end of 2016. The semiarid highlands surrounding the capital rely mostly on replenishment by rainfall and, secondarily on glacial meltwater (20%–28%), especially during the winter season. But glaciers such as Chacaltaya, which hosted the highest ski resort in the world (17 785 feet) and provided water to La Paz and El Alto, melted completely. In 2005, only a few patches of snow/ice were left, and in 2009 it dissapeared completely (Soruco et al. 2015; Escurra et al. 2014).

Others glaciers have lost a great part of their mass and continue melting. Although the average water use in El Alto is low (52 liters person^{-1} day^{-1}), the critical situation of water supply may worsen as the population migrating to the city increases, especially during drought episodes when food security is no longer guaranteed in the countryside and with the growing demand of water for irrigation for agriculture in the surrounding areas.

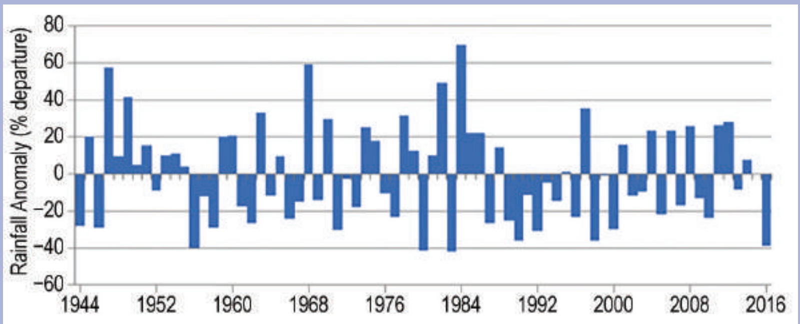

Fig. SB7.4. Jan–Apr precipitation anomalies (%; 1981–2010 base period) for Cochabamba, Bolivia, during 1944–2016 (Source: SENAMHI-Bolivia.)

general population with water and electricity shortages, and dependent on water being transported to them. During most of 2016, western Amazonia was dominated by drier conditions, and in the state of Acre rainfall was about 85% of the 1961–90 average annual rainfall of 1947.5 mm. The Rio Acre levels were 1.41 m on 4 August, the lowest level since 1970. The Rio Madeira, at Porto Velho, was just 2.98 m high on 5 August, its lowest level in 48 years; the level dropped even more—to 1.9 m at Porto Velho on 30 September, the lowest value in 2016. The Ucayali River in the Peruvian Amazon reached 85 m on 22 September, its lowest level in 23 years. This was due to below-average rainfall of about 400 mm month^{-1} in western Amazonia during the first half of 2016.

Problems related to rainfall deficits and subsequent low water supplies were particularly intense in the central Andes, and this situation is considered the worst drought Bolivia has seen for 25 years (see Sidebar 7.2).

3) Southern South America—M. Bidegain, J. L. Stella, M. L. Bettolli, and J. Quintana

This region includes Argentina, Chile, and Uruguay.

(i) Temperature

Near or below-normal temperatures were observed over most of southern South America during 2016, with mean temperature anomalies between −0.5° and +0.5°C (see Fig. 7.13a). The 2016 mean temperature anomalies for Argentina and Uruguay were +0.1°C and −0.4°C, respectively. Argentina's 2016 mean temperature anomaly was its coolest since 2011, breaking the streak of four consecutive years (2012–15) with record or near-record high temperatures. Chile had the largest positive anomaly at +0.7°C.

Summer (December–February) 2015/16 was warmer than normal across northern and central Argentina, Chile, and Uruguay, with temperature anomalies 0.5°–1.0°C above average.

Mean temperatures for autumn (March–May) were 0.5°–1.0°C below average in northern and central Argentina, central Chile, and Uruguay. Conversely, northwestern Patagonia experienced warmer-than-average anomalies of greater than +1°C. For Argentina, its autumn mean temperature was the sixth lowest since national records began in 1961, with average maximum temperatures that were record low. Of note, the average mean temperature for April was much above average for northeastern Argentina (+1°C), Uruguay (+0.8°C), and northern Chile (+0.7°C), while much-below-average anomalies (−2.0°C) were observed across southern Argentina and Chile. Cooler-than-average conditions occurred across much of Argentina and Uruguay during May, with several locations setting new monthly low average maximum temperature records. Meanwhile, central Chile had above-average temperatures.

Winter (June–August) was characterized by cooler-than-average conditions across northeastern Argentina and Uruguay, with above-average conditions across central and southern Chile and western and southern Patagonia (+1.3°C).

Below-average conditions continued during spring (September–November) for northeastern Argentina and northern Uruguay (−0.2°C to −0.5°C anomalies). Above-average temperatures returned to the region in December for the first time since February, particularly notable over central Chile, Argentina, and Uruguay.

(ii) Precipitation

The 2016 annual rainfall anomaly in Argentina and Uruguay was +14.3% and +9%, respectively (see Fig. 7.13b). Although the annual rainfall was above average, drier-than-average conditions were observed across central and northeastern Argentina, northern Uruguay, and central Chile during the second half of the year, following the influence of the cold phase of ENSO.

Several events in April brought abundant rainfall to northeastern Argentina and Uruguay, with several stations setting new monthly precipitation records. In central Chile, Santiago had its wettest April since 1878, accumulating 109 mm, which is nearly seven times the monthly average. The extreme precipitation was associated with the strong El Niño that developed in 2015 and dissipated in May 2016, and impacted the Rio de la Plata basin with above-average rainfall during summer and fall.

During autumn, there were two zones with excess precipitation: central-western Argentina, where precipitation totals for April–May were the most significant for the year; and central-eastern Argentina and western Uruguay, with April rainfall totals contributing the largest portion of the annual precipitation total. The much-above-average precipitation during April resulted in devastating floods.

During spring, much of southern South America observed below-normal precipitation, with the exception of areas in northern Patagonia and central and northern Argentina which had above-average precipitation in October. Accumulated rainfall anomalies during October were as high as +200 mm in an extensive area that included central-western