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-

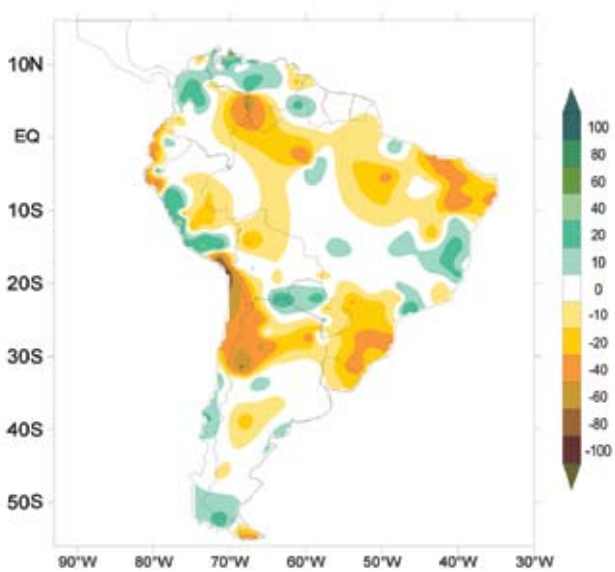

Fig. 6.19. South American 2006 annual precipitation anomalies (mm, 1979–2000 base) from CAMS-OPI.

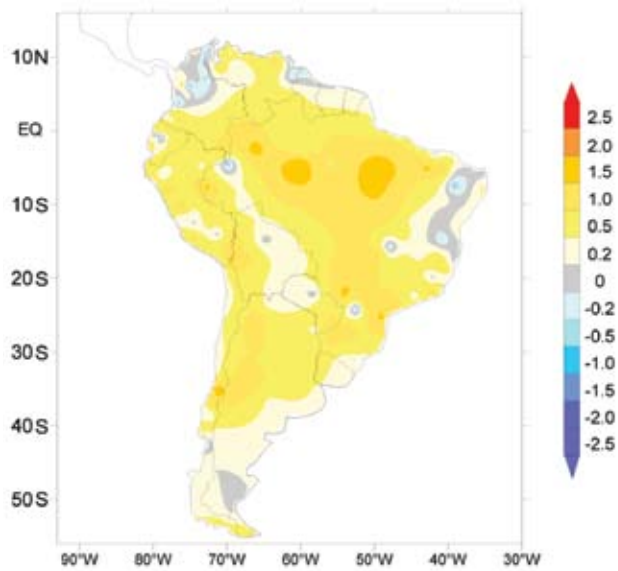

Fig. 6.20. South American 2006 annual temperature anomalies (°C, 1971–2000 base) from CAMS-OPI.

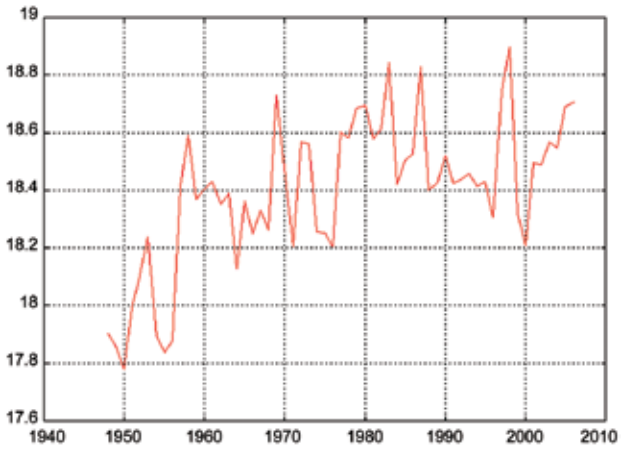

Fig. 6.21. Time series of annually averaged air temperature (°C), spatially averaged from 15°N to 55°S and 30° to 90°W, for the 1948–2006 period. [Source: NCEP–NCAR reanalysis at www.cdc.noaa.gov/cgi-bin/Composites/.]

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

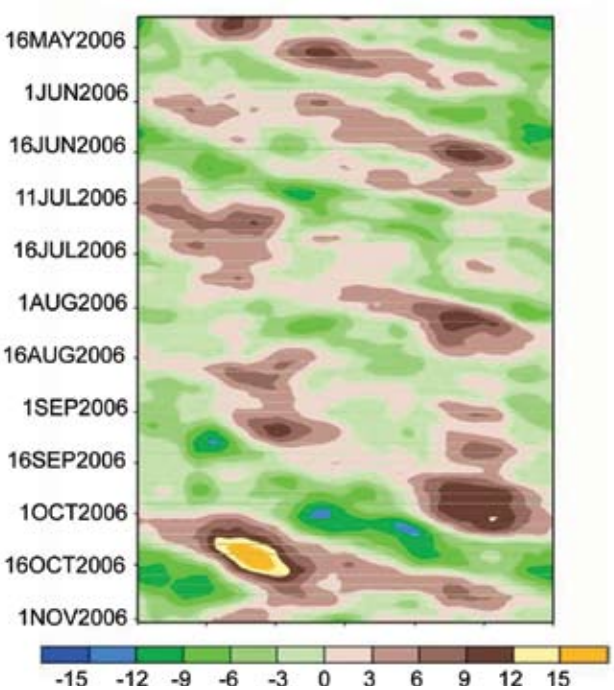

Fig. 6.22. Hovmöller diagram, averaged from 5°S to 5°N, of 200-hPa velocity potential anomalies. [Source: www.cpc.ncep.noaa.gov/products/.]

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

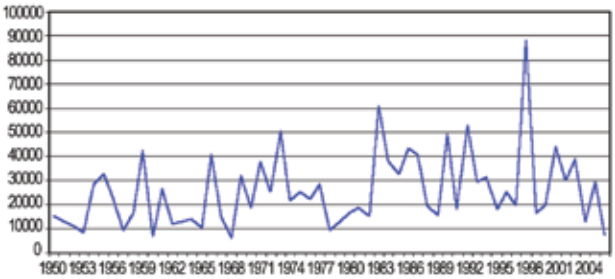

Fig. 6.23. Seasonal January–June discharge ($m^3 s^{-1}$) of the Uruguay River at Salto Grande during 1950–2006.

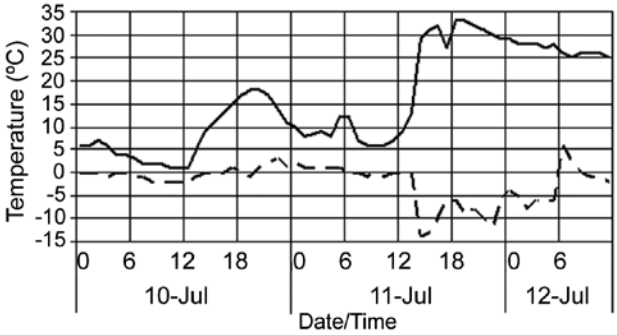

Fig. 6.24. Hourly evolution of surface temperature (°C) and dewpoint temperature (°C) in San Juan, Argentina.

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