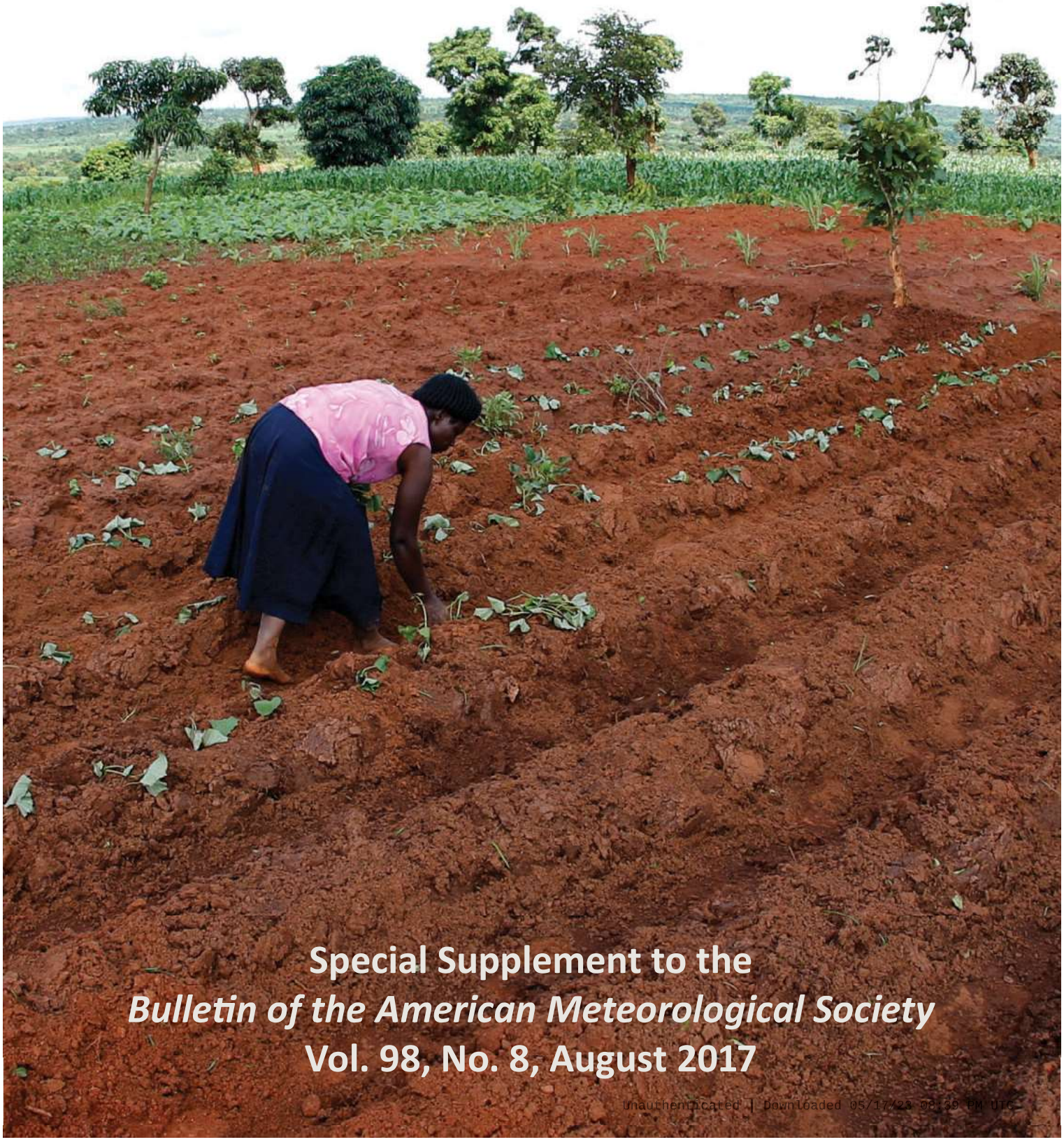
STATE OF THE CLIMATE IN 2016



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STATE OF THE CLIMATE IN 2016

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Malawian subsistence farmer Rozaria Hamiton plants sweet potatoes near the capital Lilongwe, Malawi, 1 February 2016. Late rains in Malawi threaten the staple maize crop and have pushed prices to record highs. About 14 million people face hunger in Southern Africa because of a drought that has been exacerbated by an El Niño weather pattern, according to the United Nations World Food Programme.

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to the warmest summer (June–August) on record, surpassing the previous record set in 2013 by +0.1°C.

Regionally, temperatures in 2016 were above average across most of the country (Fig. 7.8a), although some areas in the north and central regions experienced cooler-than-average conditions. Twelve of 31 states had their warmest year on record: Sinaloa, Durango, Nuevo Leon, and Tamaulipas (northern Mexico); Aguascalientes, Colima, Hidalgo, Jalisco, Queretaro, and Tlaxcala (central Mexico); and Campeche and Chiapas (southern Mexico).

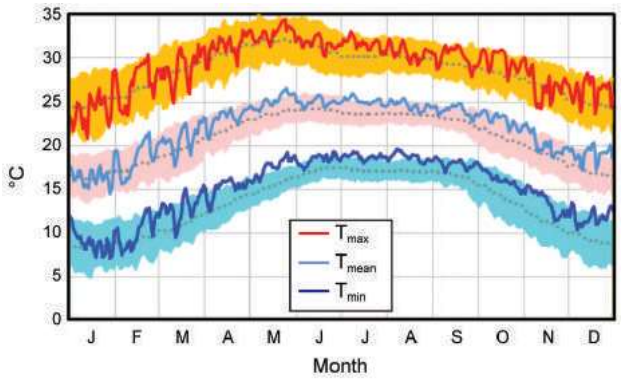

Fig. 7.7. Nationwide daily temperatures (°C; 1981–2010 base period) for Mexico in 2016. Shaded areas represents the ±2 std. dev. Solid lines represents daily values for the three temperature parameters and dotted lines are the climatology. (Source: National Meteorological Service of México.)

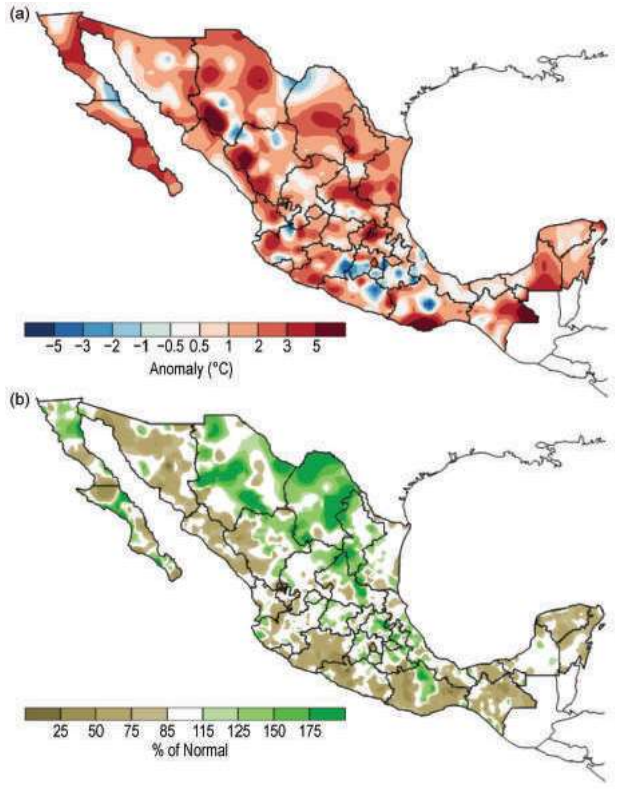

Fig. 7.8. (a) 2016 mean temperature anomalies (°C; 1981–2010 base period) over Mexico and (b) 2016 precipitation anomalies (% of normal). (Source: National Meteorological Service of México.)

(ii) Precipitation

Above-average rainfall was observed in northern, northeastern, and central regions in 2016, while below-average precipitation was evident across the Pacific coast, the south, and southeast (Fig. 7.8b). The 2016 average rainfall total of 744.1 mm (94.7% of normal) was the 15th driest since records began in 1971. Regionally, states in the south and southeast had exceptionally low precipitation totals, with Oaxaca and Tabasco (both in southern Mexico) each experiencing their third driest year on record. In contrast, Coahuila (northern Mexico) had its third wettest year, behind 2004 and 2010.

August was the wettest month of the year. Hurricane Earl and Tropical Storm Javier brought significant precipitation to the country in early August. Mexico's precipitation total in August 2016 ranked as the sixth wettest in the national records since 1971.

(iii) Notable events and impacts

Eleven tropical cyclones affected Mexico in 2016, which is four less than the 1971–2012 average of 15. Three tropical cyclones were near land or made landfall from the Caribbean or Atlantic basin (average for this basin is five tropical cyclones). Tropical Storm Danielle and Hurricane Earl made landfall on 5–7 June and 2–6 August, respectively. Tropical Storm Colin formed north of the Yucatan Peninsula and tracked toward the southeast United States in early August. Eight cyclones were near land or made landfall from the Eastern North Pacific basin (average for this basin is 10). This value is lower than the number of storms that impacted the nation from the same basin during 2014 and 2015, when there were 14 and 9 systems, respectively. The low number of Eastern North Pacific storms contributed to the below-average precipitation on the Pacific side of the country in 2016.

c. Central America and the Caribbean

1) Central America—J. A. Amador, H. G. Hidalgo, E. J. Alfaro, A. M. Durán-Quesada, B. Calderón, N. Mora, and D. Arce

For this region, nine stations from five countries were analyzed (Fig. 7.9). Stations on the Caribbean slope are: Philip Goldson International Airport,

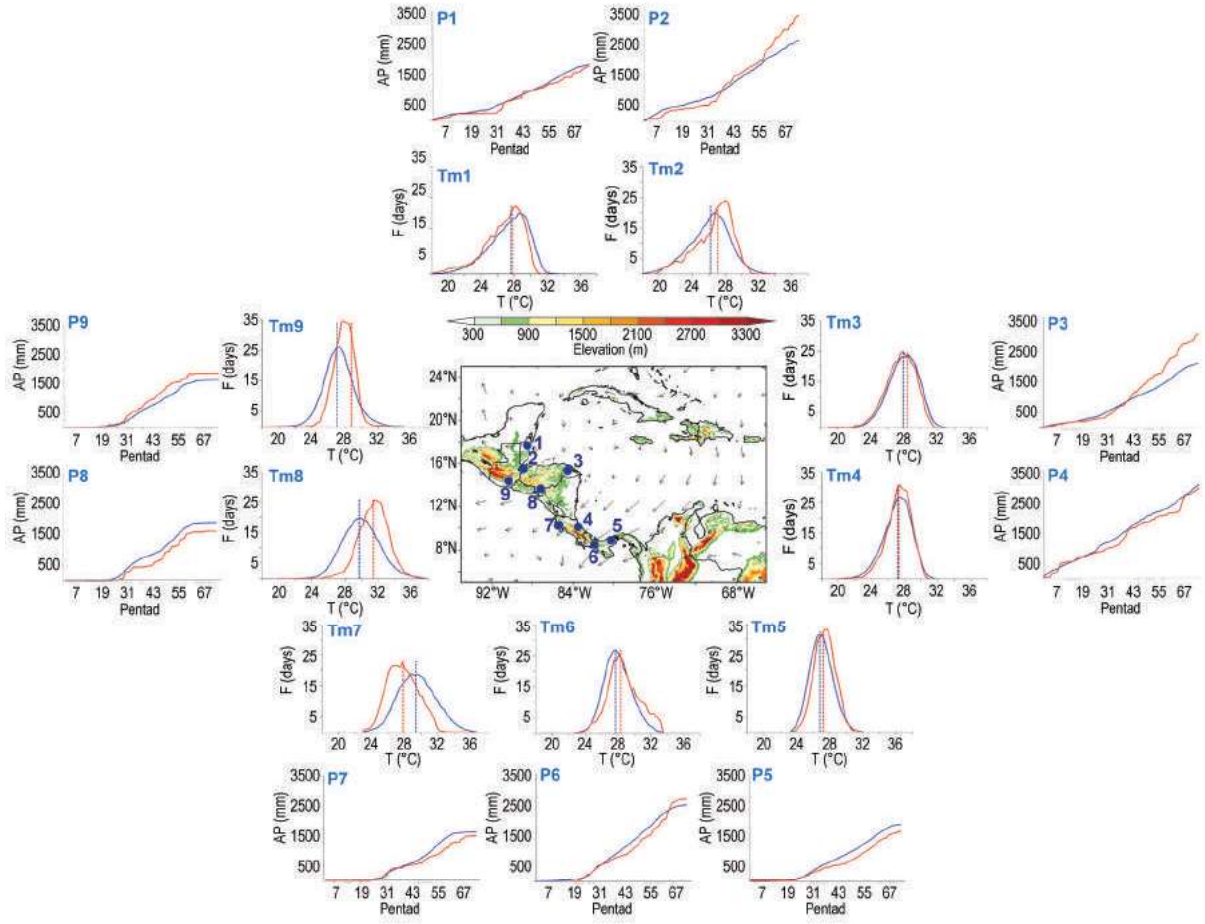

Fig. 7.9. Mean surface temperature (Tm; °C) frequency (F; days) and accumulated pentad precipitation (AP; mm) time series are shown for nine stations (blue dots) in Central America: (1) Philip Goldson International Airport, Belize; (2) Puerto Barrios, Guatemala; (3) Puerto Lempira, Honduras; (4) Puerto Limón, Costa Rica; (5) Tocumen International Airport, Panama; (6) David, Panama; (7) Liberia, Costa Rica; (8) Choluteca, Honduras; and (9) Puerto San José, Guatemala. The blue solid line represents the 1981–2010 average values and the red solid line shows 2016 values. Vertical dashed lines show the mean temperature for 2016 (red) and the 1981–2010 period (blue). Vectors indicate July wind anomalies at 925 hPa (1981–2010 base period). Shading depicts regional elevation (m). (Data sources: NOAA/NCEI and Central American NWS.)

Belize; Puerto Barrios, Guatemala; Puerto Lempira, Honduras; and Puerto Limón, Costa Rica. Stations located on the Pacific slope are: Tocumen International Airport and David, Panama; Liberia, Costa Rica; Choluteca, Honduras; and Puerto San José, Guatemala. Precipitation and temperature records for the stations analyzed were provided by Central American National Weather Services (NWS). Anomalies are reported using a 1981–2010 base period and were calculated using NWS data. The methodologies used for all variables can be found in Amador et al. (2011).

(i) Temperature

With the exception of Belize, the mean temperature (Tm) frequency distributions (Fig. 7.9) for the climatology and for 2016 are significantly different from each other at the 95% confidence level, according to a two-sample Kolmogorov–Smirnov goodness-of-fit hypothesis test (Wilks 2011). Anomalously high mean temperatures were observed for most of the stations analyzed, with the largest positive anomalies in Puerto Barrios (Tm2), Choluteca (Tm8), and San José (Tm9). For most stations, the 2016 higher-than-average means were the result of more frequent warm (but not extreme) days.

(ii) Precipitation

The accumulated pentad precipitation (P; mm) time series are shown for the nine stations in Central America in Fig. 7.9. David (P6) and San José (P9) on the Pacific slope, and Puerto Barrios (P2) and Puerto Lempira (P3) on the Caribbean slope recorded above-average precipitation accumulations for 2016. Puerto Lempira had extremely high accumulations

(at the 95% confidence level) at the end of the year that were due to large rainfall contributions after pentad 40 (approximately late September). Frequent rains after pentad 40 helped Puerto Barrios end the year with a large positive anomaly. Conversely, Tocumen (P5), Liberia (P7), and Choluteca (P8) in the Pacific, and Belize (P1) and Limón (P4) in the Caribbean experienced below-average accumulations. The year 2016 marked the fourth consecutive year of drought conditions in Liberia. Of all stations analyzed, Tocumen experienced the most severe drought conditions in 2016.

Low-level moisture transport (computed based on ERA-Interim reanalysis data) followed climatology as the 2016 ENSO signal decreased its intensity, with dry conditions until the transition to the first part of the rainy season (May–June). Moisture flux divergence showed a mild second part of the rainy season (September–November), which started about three weeks late. Low-level circulations in the region showed a stronger-than-average Caribbean low-level jet (Amador 1998) 925-hPa winds during July (vectors in Fig. 7.9), consistent with positive multivariate ENSO index values during that period (Amador et al. 2006).

(iii) Notable events and impacts

Three tropical cyclones affected Central America in 2016, all from the Caribbean Basin. Hurricane Earl made landfall in Belize on 4 August and crossed the isthmus through Guatemala the same day. More than 9000 people were affected by heavy rain and floods in these two countries. Hurricane Matthew was present in the Caribbean Sea from 28 September to 6 October, reaching category 5 intensity by 1 October, but its main impacts were in the Greater Antilles. Hurricane Otto made landfall between Costa Rica and Nicaragua on 24 November and passed over the isthmus during 24–25 November. In Costa Rica, Hurricane Otto directly impacted the northern cities and indirectly impacted the southern Pacific slope communities. For Panama, Costa Rica, and Nicaragua, the impacts of Otto were severe, affecting nearly 25 000 people, with 18 fatalities and more than 2400 damaged homes. For additional information on the impacts from these storms and other hydrometeorological events, please refer to Online Table S7.1.

Hurricane Otto was a remarkable meteorological event, breaking several historical records. Otto was the strongest hurricane on record so late in the year, the latest hurricane on record to be located in the Caribbean Sea, and the only known hurricane to move over Costa Rica (Brown 2017). Also, this was the first time that a significant amount of lightning activity (a known proxy for convection) from a hurricane has been documented in this region. Convection associated with Otto produced abundant lightning activity and precipitation in Nicaragua and Costa Rica with large socioeconomic impacts (Online Table S7.1). The World Wide Lightning Location Network (WWLLN), a real-time network with global coverage, was used to depict Hurricane Otto's lightning activity develop-

Table 7.1. Record annual temperatures (°C) for some Caribbean locations.

Country	Station Name/ Location	Year records began	Min temp (°C)	Max temp (°C)	Mean temp (°C)
Barbados	CIMH	1971	24.2	—	27.3
Cayman	METEO	1976	25.3	—	—
Dominica	Canefield	1982	—	31.8	—
Dominica	Douglas Charles	1982	—	—	27.6
Jamaica	Sangster	1973	24.5	—	—
Jamaica	Worthy Park	1973	—	—	24.9
Puerto Rico	Lajas	1971	20.6	—	26.4
Puerto Rico	Aibonito	1971	19	—	—
St. Kitts	Golden Rock	1998	—	—	28
St. Lucia	Hewanorra	1979	25.6	—	—
Trinidad	Piarco	1946	—	—	27.8
Tobago	Crown Point	1969	25.4	—	27.9
USVI	St. Thomas	1953	25.5	—	—

ment some hours before the storm made landfall near Costa Rica and Nicaragua. Figure 7.10 reveals a highly asymmetric structure of the lightning distribution along the northern highly convective rainbands. Otto seemed to intensify its lightning activity not only after strengthening to a category 3 hurricane (not shown) but also as it approached land, as has been found in previous studies (e.g., Solorzano et al. 2008). The period shown in Fig. 7.10 corresponds to Hurricane Otto some hours after its intensification phase from a tropical storm to a hurricane on 23 November near 1800 UTC (Brown 2017). Figure 7.10 also shows the western movement of the convective rainbands with respect to Otto's center (yellow triangles) for three different hourly periods. Otto's track was estimated from the National Hurricane Center best track information.

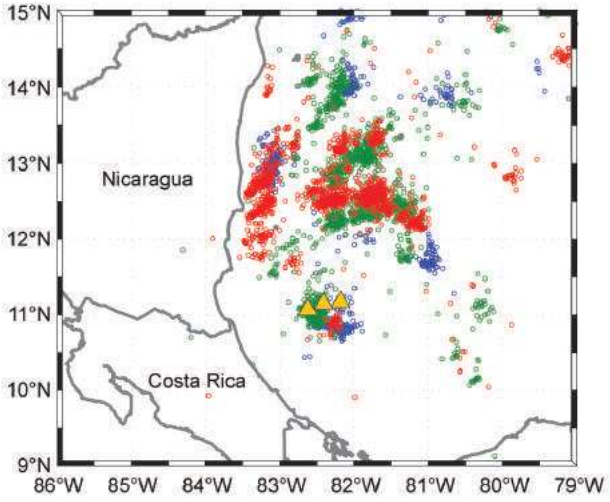

Fig. 7.10. Lightning activity associated with Hurricane Otto showing the northern rainbands moving westward from 0400 to 0459 UTC (blue open circles), from 0600 to 0659 UTC (green open circles) and from 0800 to 0859 UTC (red open circles). Yellow triangles represent the approximate westward track of Otto at 0400, 0600, and 0800 UTC estimated from the National Hurricane Center best track information. Data is from the WWLLN global data base (http://webflash.ess.washington.edu/).

2) Caribbean—T. S. Stephenson, M. A. Taylor, A. R. Trotman, C. J. Van Meerbeeck, A. O. Porter, S. Etienne–LeBlanc, M. Hernández, I. T. Gonzalez, V. Cutié, D. Boudet, C. Fonseca, S. Willie, J. M. Spence, K. Kerr, A. Aaron-Morrison, G. Tamar, R. Stennett-Brown, and J. D. Campbell

(i) Temperature

Warmer-than-average conditions persisted throughout the Caribbean during 2016 (Fig. 7.11a). This was likely related to the El Niño conditions that lasted through May 2016 and year-long above-average Caribbean sea surface temperatures. A number of station temperature records were observed (Table 7.1). Additionally, the annual mean temperature for Cuba (26.2°C) was the fourth highest since 1951. Trinidad's Piarco Airport recorded its second-warmest year (28.4°C), with its second highest annual mean maximum temperature (31.7°C) and third highest annual mean minimum temperature (23.1°C) since records began in 1946. Monthly mean maximum temperatures were record high for July (33.4°C) and October (34.3°C). Similarly, daily extreme temperature records included the highest daily maximum temperature for April (36.3°C) and October (36.2°C). Other notable Trinidadian records include March's second highest daily maximum temperature (35.5°C) on 12 March, behind 1 March 2010 (35.7°C), and July's second

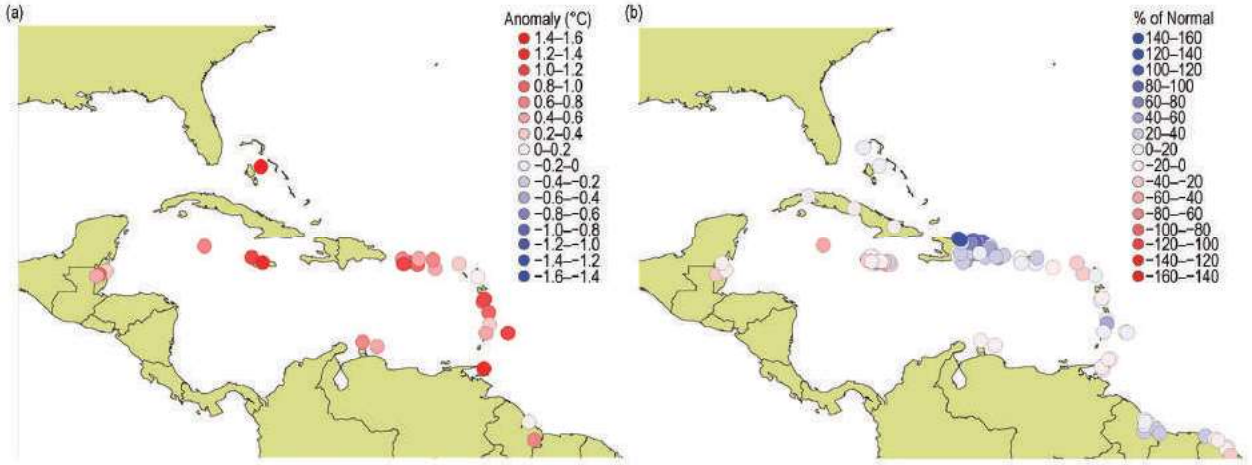

Fig. 7.11. (a) Temperature anomalies (°C) and (b) precipitation anomalies (%) rainfall for 2016 across the Caribbean basin with respect to the 1981–2010 annual mean. (Source: Caribbean Institute for Meteorology and Hydrology.)