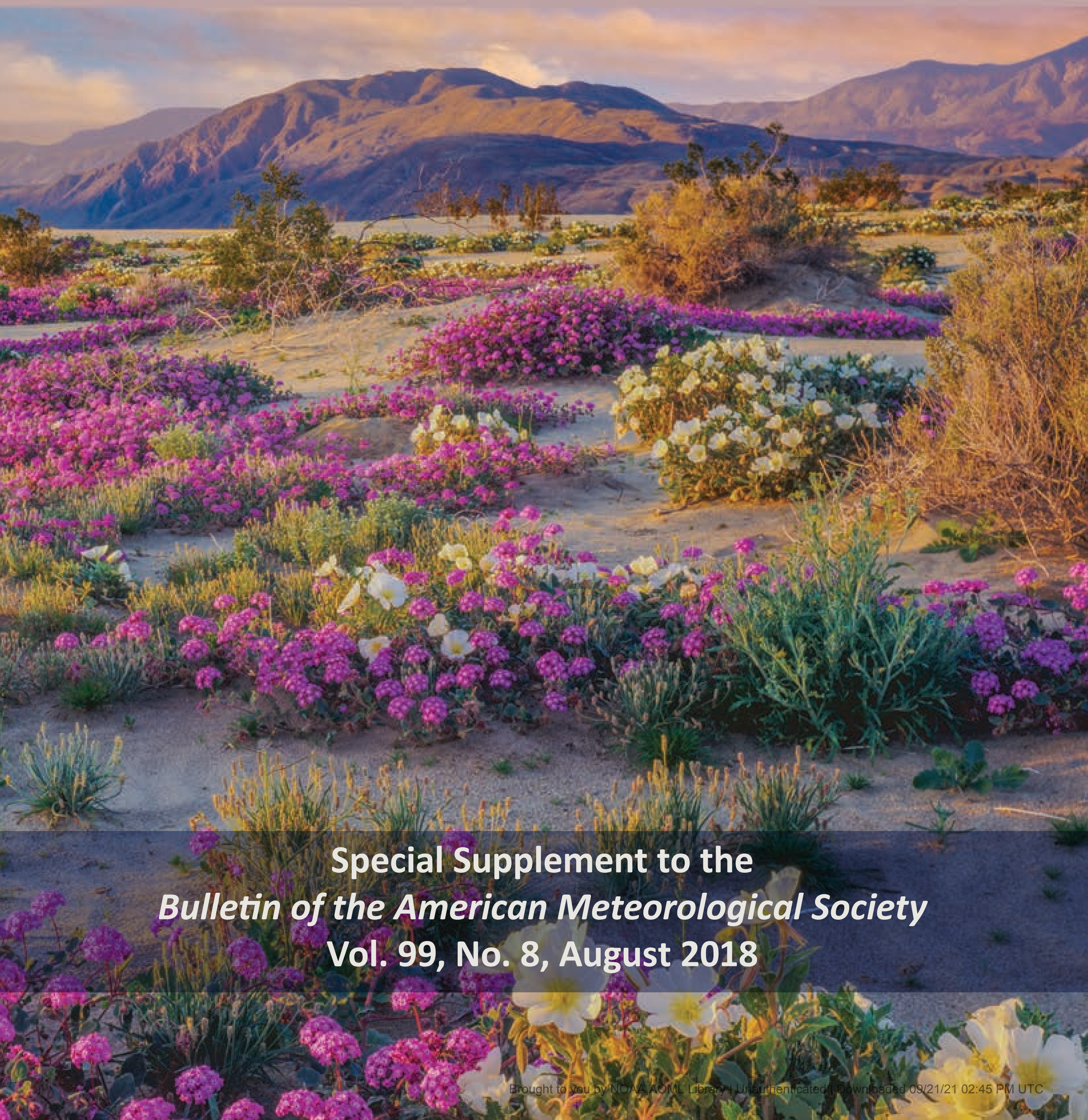
STATE OF THE CLIMATE IN 2017



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speeds ≥ 137 kt or 70.5 m s^{-1}), which is one less than in 2016 and five fewer than in 2015. The three 2017 storms were Hurricanes Irma and Maria in the North Atlantic and Super Typhoon Noru in the western North Pacific. Sidebars 4.1 and 4.3 detail the records set and devastating local impacts of Irma and Maria, respectively.

Several other Saffir–Simpson category 3 and 4 intensity level systems during 2017 also had major impacts, including: (1) Hurricane Harvey in the North Atlantic, (2) Typhoons Tembin and Hato in the western North Pacific, and (3) Tropical Cyclone Debbie in the Australian basin. Also noteworthy was the development of Tropical Cyclone Donna in the southwest Pacific basin in early May 2017, a date which is outside of the formal TC season for that basin. Donna became the most intense TC recorded in that basin during the month of May.

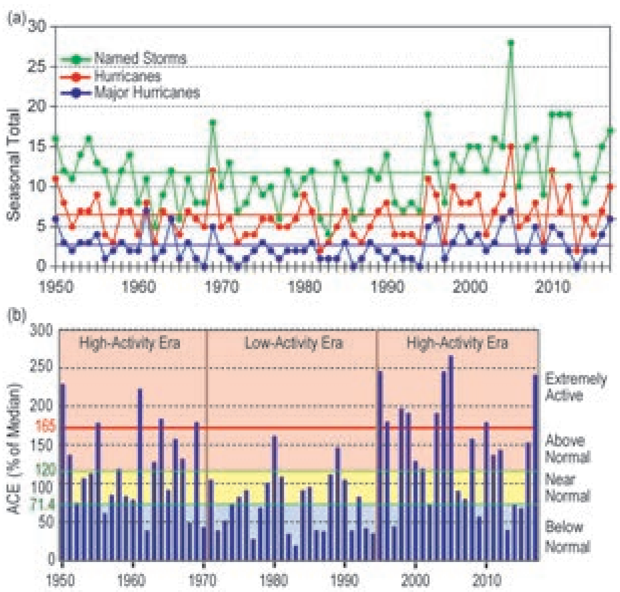

Fig. 4.19. Seasonal Atlantic hurricane activity during 1950–2017 based on HURDAT2 (Landsea and Franklin 2013). (a) Number of named storms (green), hurricanes (red), and major hurricanes (blue), with 1981–2010 seasonal means shown by solid colored lines. (b) ACE index expressed as percent of the 1981–2010 median value. ACE is calculated by summing the squares of the 6-hourly maximum sustained surface wind speed (knots) for all periods while the storm is at least tropical storm strength. Red, yellow, and blue shadings correspond to NOAA's classifications for above-, near-, and below-normal seasons, respectively (www.cpc.ncep.noaa.gov/products/outlooks/background_information.shtml). The thick red horizontal line at 165% ACE value denotes the threshold for an extremely active season. Vertical brown lines separate high- and low-activity eras.

2) Atlantic basin—G. D. Bell, E. S. Blake, C. W. Landsea, S. B. Goldenberg, and R. J. Pasch

(i) 2017 Seasonal activity

The 2017 Atlantic hurricane season produced 17 named storms, of which 10 became hurricanes and 6 of those became major hurricanes (Fig. 4.19a). The HURDAT2 30-year (1981–2010) seasonal averages are 11.8 tropical (named) storms, 6.4 hurricanes, and 2.7 major hurricanes (Landsea and Franklin 2013).

The 2017 seasonal ACE value (Bell et al. 2000) was about 241% of the 1981–2010 median (92.4 × 10^4 kt^2; Fig. 4.19b). This value is well above NOAA's thresholds for an above-normal season (120%) and an extremely active season (165%), www.cpc.ncep.noaa.gov/products/outlooks/background_information.shtml.

This ACE value makes 2017 the most active season since 2005, and the first extremely active season since 2010. It also makes 2017 the fourth most activeseason since at least 1950 and the seventh most active season in the historical record (since 1854). However, it should be noted that reliable basin-wide records for exact season-to-season comparisons with ACE began in the mid-1970s with the advent of the geostationary satellite era (Landsea et al. 2006).

The occurrence of above-normal and extremely active seasons shows a strong multidecadal signal. The 2017 season is the 15th above-normal season and the 9th extremely active season since the current high-activity era for Atlantic hurricanes began in 1995. The previous Atlantic high-activity era (1950–70) also featured numerous above-normal and extremely active seasons. In stark contrast, the intervening low-activity era of 1971–94 featured only two above-normal seasons, and none were extremely active (Goldenberg et al. 2001).

(ii) Storm formation regions, tracks, and landfalls

A main delineator between above-normal and below-normal Atlantic hurricane seasons is the number of hurricanes and major hurricanes that develop from storms that are named while in the main development region (MDR, green boxed region in Fig. 4.21a) spanning the tropical Atlantic Ocean and Caribbean Sea between 9.5° and 21.5°N (Goldenberg and Shapiro 1996; Goldenberg et al. 2001; Bell and Chelliah 2006). When activity is high in the MDR, overall seasonal TC activity and ACE are also high. The vast majority of storms which form within the MDR do so during the peak months (August–October, ASO) of the season. This peaked climatology is why seasonal hurricane predictions are essentially based on predictions for ASO of the atmospheric and oceanic conditions within the MDR (Goldenberg and Shapiro 1996; Klotzbach et al. 2017).

During 2017, seven of the ten Atlantic hurricanes and five of the six major hurricanes first became named storms during ASO in the MDR. For the season as a whole, MDR-originating storms produced an ACE of 212% of the 1981–2010 median and accounted for 86% of the total season's ACE. The strongest and longest-lived MDR storm of the season was Major Hurricane Irma, which developed in late August and by itself produced an ACE value of 77.5% of the 1981–2010 median. Only one storm in the satellite record since 1966 (Major Hurricane Ivan in 2004) produced a larger ACE.

Extremely active seasons have a higher frequency of landfalling tropical storms, hurricanes, and major hurricanes. During 2017, there were 13 separate storm landfalls for the basin as a whole. This count reflects ten distinct named storms, of which six formed in the MDR. These six MDR storms include all three landfalling major hurricanes and two of the three (excluding Nate which formed in the extratropics) landfalling non-major hurricanes.

Six named storms struck the United States during 2017, including three catastrophic major hurricanes (Harvey in Texas, Irma in Florida, and Maria in Puerto Rico and the U.S. Virgin Islands), one non-major hurricane (Nate in Louisiana/ Mississippi), and two tropical storms (Cindy in Texas and Emily in Florida). Harvey was the first continental U.S. landfalling major hurricane since Wilma struck Florida in October 2005.

From a historical perspective, 86% (12 of 14 seasons) of extremely active seasons during 1950–2017 featured at least two continental U.S. landfalling hurricanes (Fig. 4.20a). This rate far exceeds the 50% rate (7 of 14 seasons) for above-normal seasons that were not extremely active and is almost triple the rate (30%, 6 of 20 seasons) for near-normal seasons. Only 5% (1 of 20 seasons) of the below-normal seasons since 1950 produced multiple continental U.S. landfalling hurricanes. Similarly, 71% (10 of 14 seasons) of extremely active seasons since 1950 featured at least one major hurricane landfall in the continental U.S (Fig. 4.20b). This is more than double the 31% rate (17 of 54 seasons) of landfalling major hurricanes for all other seasons combined. Interestingly, about 20% of below-normal seasons have had a continental U.S. landfalling major hurricane.

The entire region around the Caribbean Sea also typically sees an increased number of hurricane landfalls during extremely active seasons. During 2017, eight named storms struck the region. These included two catastrophic major hurricanes (Irma and Maria), two non-major hurricanes (Franklin and Katia in eastern Mexico), and four tropical storms (Bret in Trinidad and Venezuela; Harvey in Barbados and St. Vincent; Nate in Central America; and Philippe in Cuba).

(iii) Atlantic sea surface temperatures

SSTs were above average during ASO 2017 across the MDR, the Gulf of Mexico, and much of the extratropical North Atlantic (Fig. 4.21a). The area-averaged SST anomaly within the MDR was +0.54°C (Fig. 4.21b). The area-averaged SST anomaly within the Caribbean Sea, a subregion of the MDR, was +0.60°C. This departure for the Caribbean Sea was the second highest since 1950 and followed the record warmth of ASO 2016 (Fig. 4.21c).

Historically, when assessing links between Atlantic SSTs and hurricane season strength, it is important to consider their common relationships to larger-scale climate patterns. Two key climate patterns are the Atlantic multidecadal oscillation (AMO; Enfield and Mestas-Nuñez 1999; Goldenberg et al. 2001; Bell and Chelliah 2006; Bell et al. 2011, 2012) and ENSO (Gray 1984; Tang and Neelin 2004; Bell and Chelliah 2006). These SST-based phenomena strongly control large-scale atmospheric conditions (such as vertical wind shear, trade winds, moisture, atmospheric sta-

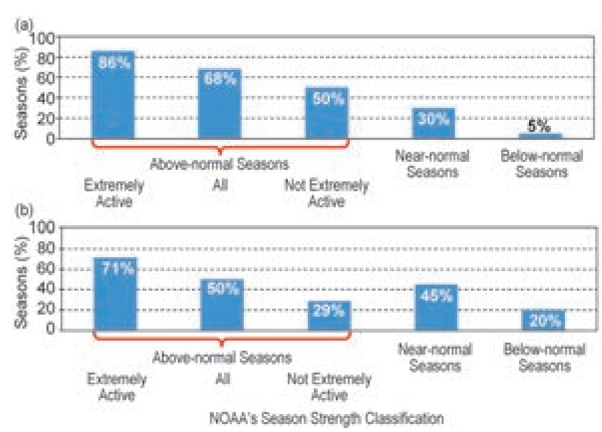

Fig. 4.20. Continental U.S. landfalling hurricane frequencies during 1950–2017 for each of NOAA's season types. (a) Percent of specified season type with at least two U.S. hurricane landfalls, and (b) percent of specified season type with one or more U.S. major hurricane landfall. Above-normal seasons include those labeled "Extremely Active" and "Above Normal Not Extremely Active." Season classifications are shown in www.cpc.ncep.noaa.gov/products/outlooks/background_information.shtml. Landfall data is based on HURDAT2 (Landsea and Franklin 2013).

bility, etc.) across the MDR, thereby influencing the strength of the hurricane season.

The AMO predisposes the ocean–atmosphere system to be either more or less conducive to Atlantic hurricane activity for periods of 25–40 years at a time. One measure of the AMO is the standardized time series of the detrended Kaplan AMO index (www.esrl.noaa.gov/psd/data/correlation/amon.us.long.data). For ASO 2017, that index was +1.51 standard deviation (std. dev.), indicating the positive (i.e., warm) phase of the AMO. The standardized 7-year running mean (using ASO seasons only) of the detrended Kaplan AMO index for ASO 2017 was +1.75 std. dev. (Fig. 4.22a). Historically, the warm AMO is associated with the Atlantic high activity eras of 1950–70 and 1995–present. Conversely, the Atlantic low activity eras of 1900–20 and 1971–94 were associated with the negative (i.e., cool) phase of the AMO.

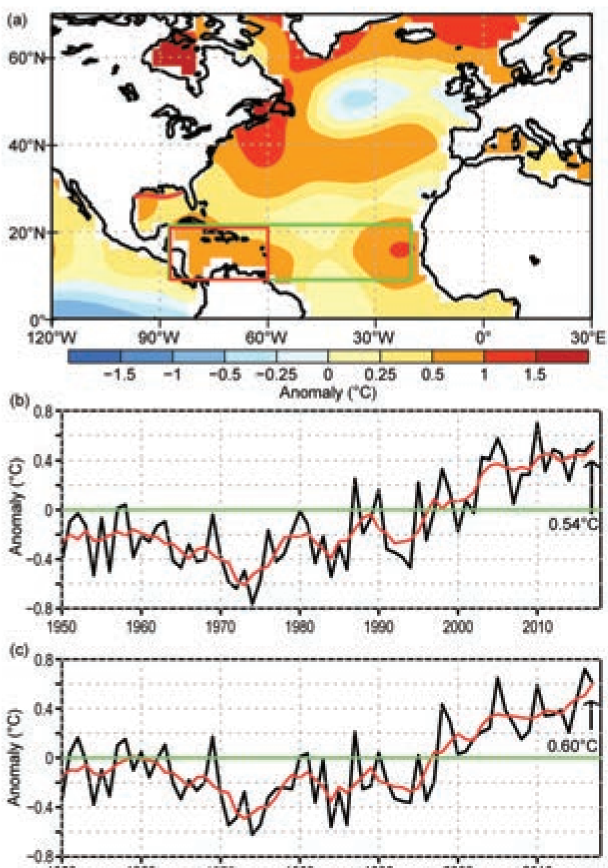

FIG. 4.21. (a) ASO 2017 SST anomalies (°C). (b),(c) Time series of ASO area-averaged SST anomalies (°C) in (b) the MDR [green box in (a)] and (c) the Caribbean Sea [red box in (a) spanning 60°–87.5°W and 10°–21.5°N]. Red lines in (b) and (c) show a 5-pt. running mean of each time series. Data source is ERSSTv4 (Huang et al. 2015). Anomalies are departures from the 1981–2010 monthly means.

Another complementary measure of the AMO is the standardized 5-year running mean of the difference between the area-averaged SST departure in the MDR and that of the global tropics (Fig. 4.22b, based on Vecchi and Soden 2007). The warm AMO during ASO 2017 featured an anomalously warm MDR compared to the remainder of the global tropics (0.36°C higher), a relationship seen throughout the historical record for active seasons. These observations, combined with the seasonal ACE time series (Fig. 4.19b), suggest that continuation during 2017 of the current Atlantic high-activity era was associated with the ongoing warm phase of the AMO.

Another ocean–atmosphere related factor for the 2017 Atlantic hurricane season was the development of La Niña in October (see Section 4b). La Niña is conducive to a more active Atlantic hurricane season because it reduces the vertical wind shear and decreases the atmospheric stability in the western MDR (Gray 1984; Tang and Neelin 2004). Cool neutral ENSO conditions prevailed during the other two peak months of the season (August and September).

(iv) Atmospheric conditions

The atmospheric conditions within the MDR during ASO 2017 reflected an inter-related set of anomalies which are typical of other extremely active seasons (Landsea et al. 1998; Bell et al. 1999, 2000, 2004, 2006, 2009, 2011, 2012, 2014, 2015, 2016; Goldenberg et al. 2001; Bell and Chelliah 2006; Kossin

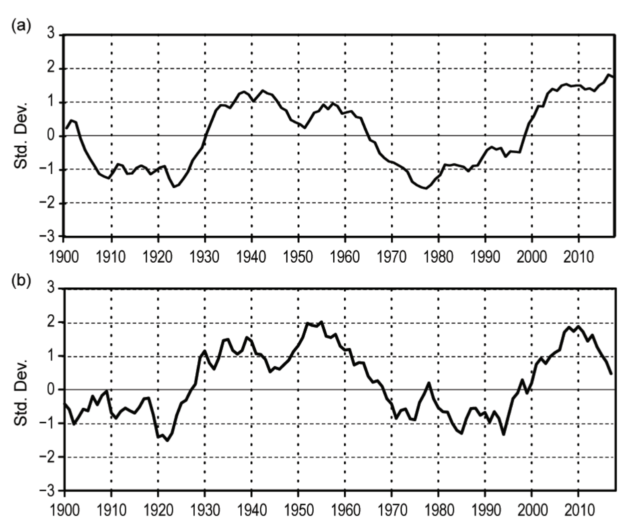

FIG. 4.22. SST time series for 1900–2017 based on ERSSTv4 (Huang et al. 2015). (a) Standardized (std. dev.) 7-yr running mean of the detrended Kaplan AMO index based on the ASO season only. (b) Standardized (std. dev.) 7-yr running mean of the difference between ASO area-averaged SST anomalies in the MDR and those for the entire global tropics (20°N–20°S).

and Vimont 2007). Historically, the combination of a warm AMO and La Niña yields the most spatially extensive set of atmospheric conditions that are conducive for Atlantic hurricane activity, while the combination of El Niño and the cool AMO yields the least conducive conditions (Bell and Chelliah 2006).

In the lower atmosphere, the conducive conditions during ASO 2017 included below-average heights/sea-level pressure (blue shading, Fig. 4.23a) across the MDR, along with weaker trade winds (i.e., westerly anomalies) extending from the eastern tropical North Pacific across the southern MDR to Africa. These westerly anomalies extended up to 700-hPa, the approximate level of the African easterly jet (AEJ), and were associated with a deep layer of anomalous cyclonic relative vorticity across the entire MDR (Fig. 4.23b). As noted by Bell et al. (2011), the increased cyclonic shear along the equatorward flank of the AEJ helps the easterly waves within the MDR to be better maintained and also provides an inherent cyclonic rotation to their embedded convective cells.

In the upper atmosphere at 200-hPa, the circulation during ASO 2017 featured an extensive and persistent ridge of high pressure across the western half of the MDR and the western North Atlantic (Fig. 4.23c). This pattern was accompanied by an eastward displacement of the tropical upper tropospheric trough (TUTT) from the western MDR to the central MDR and central North Atlantic. Consistent with this pattern, the upper-level westerly winds were weaker than average (indicated by easterly anomalies) in the western MDR along the southern flank of the anomalous ridge. The resulting vertical wind shear (Fig. 4.24a) was also weaker than average across the central and western MDR as well as in the vicinity of the Bahamas (Fig. 4.24b).

As a result, weak vertical wind shear (< 10 m s^{-1}) extended across the entire MDR from Africa to Central America, as well as northward over the western North Atlantic (Fig. 4.24a). Also, the associated steering current (Fig. 4.24a, vectors) allowed African easterly waves and named storms to track farther westward into the region of anomalously weak vertical wind shear and exceptionally warm SSTs. These conditions greatly increased the number and strength of the TCs within the MDR, as well as the number of landfalling hurricanes.

The exceptionally strong and persistent ridge over the western Atlantic was a crucial aspect of the 2017 Atlantic hurricane season. Although La Niña technically developed in October, a La Niña–like pattern of tropical convection was already present in September. The rapid response in the upper-level atmospheric circulation to the developing La Niña likely helped maintain that ridge during October–November [a period when two hurricanes (including Major Hurricane Ophelia) and two tropical storms formed] and may have contributed to the September conditions as well.

A pronounced ridge such as this was last seen in association with the record strong 2005 Atlantic hurricane season (Bell et al. 2006). Therefore, while

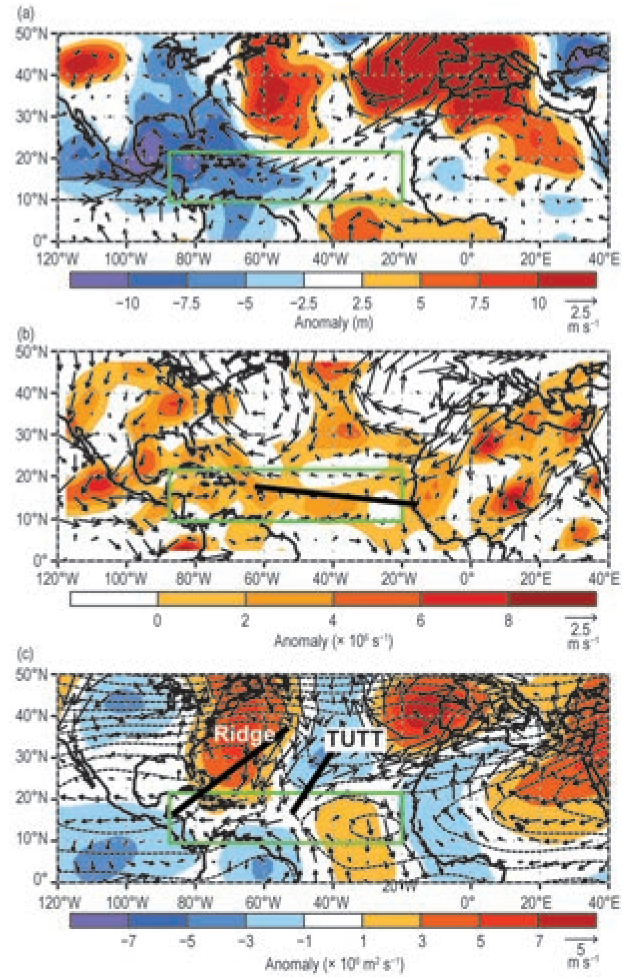

Fig. 4.23. ASO 2017: (a) anomalous 1000-hPa heights (shaded; m); (b) anomalous 700-hPa cyclonic relative vorticity (shaded; × 10^6 s^{-1}); (c) 200-hPa total streamfunction (contours, interval: 5 × 10^6 m^2 s^{-1}) and anomalies (shaded), from NCEP–NCAR reanalysis (Kalnay et al. 1996). The corresponding anomalous wind vectors (m s^{-1}) are shown in each panel. In (b), the thick solid line indicates the axis of the mean African easterly jet which was hand-drawn based on total seasonal wind speeds (not shown). In (c) the upper-level ridge and TUTT discussed in the text are labeled and denoted by thick black lines. Vector scales are below right of color bar. Green box denotes the MDR. Anomalies are departures from the 1981–2010 means.

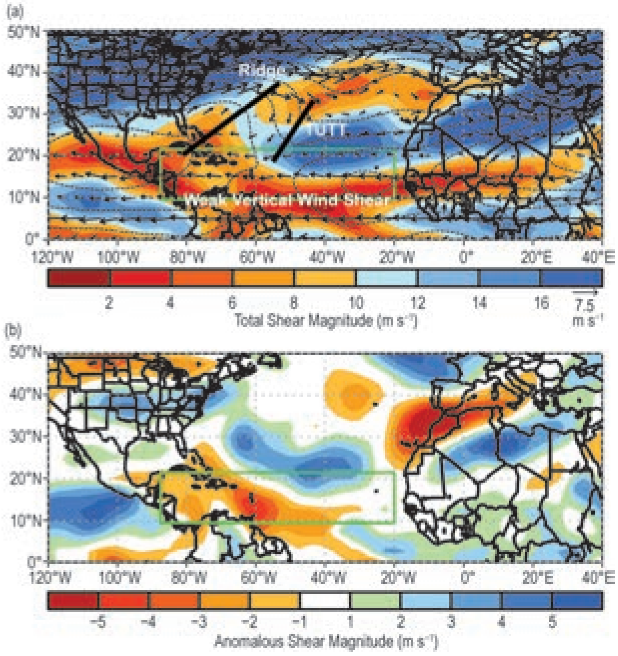

FIG. 4.24. ASO 2017: 200–850 hPa vertical wind shear magnitude (shaded; m s^{-1}) (a) total and (b) anomalies. Overlaid in (a) are the total 200-hPa streamfunction field (contours, interval: 5 × 10^{6} m^{2} s^{-1}) and the 200–850 hPa layer mean wind vectors (m s^{-1}) representing the steering current. The upper-level ridge and TUTT discussed in the text are labeled and denoted by thick black lines. Vector scale is below right of color bar. Green box denotes the MDR. Data is from NCEP–NCAR reanalysis (Kalnay et al. 1996). Anomalies are departures from the 1981–2010 means on total seasonal wind speeds (not shown). In (c) the upper-level ridge and TUTT discussed in the text are labeled and denoted by thick black lines. Vector scales are below right of color bar. Green box denotes the MDR. Anomalies are departures from the 1981–2010 means.

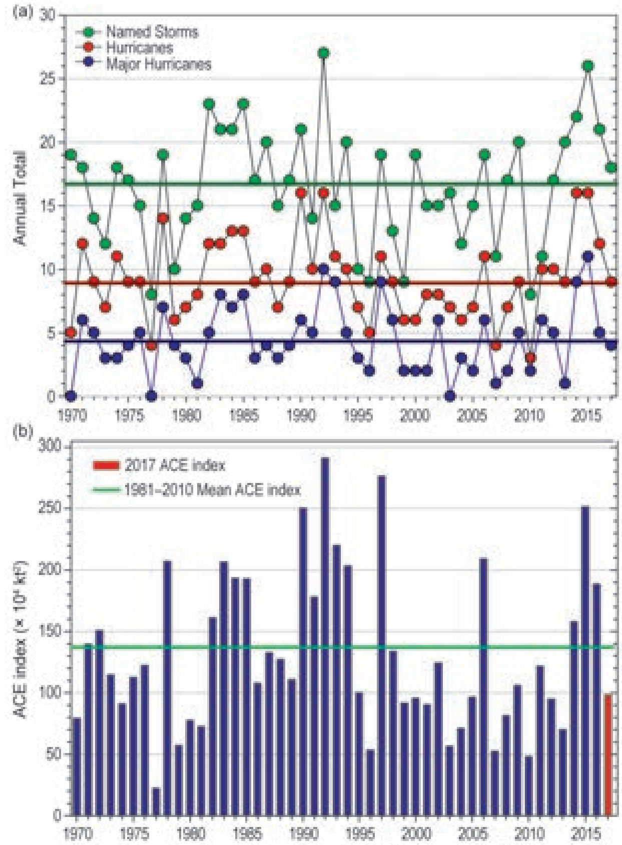

FIG. 4.25. Seasonal TC statistics for the full ENP/CNP basin over the period 1970–2017: (a) number of named storms, hurricanes, and major hurricanes and (b) the ACE index (× 10^{4} kt^{2}) with the 2017 seasonal total highlighted in red. Horizontal lines denote the corresponding 1981–2010 base period means for each parameter.

the warm AMO and La Niña set the stage for an extremely active 2017 Atlantic hurricane season, these combined climate factors alone do not likely account for the combined magnitude and duration of the western Atlantic ridge, which is seen less frequently.

3) Eastern North Pacific and Central North Pacific basins—M. C. Kruk and C. J. Schreck

(i) Seasonal activity

The eastern North Pacific (ENP) basin is officially split into two separate regions for the issuance of warnings and advisories by NOAA's National Weather Service. NOAA's National Hurricane Center in Miami, Florida, is responsible for issuing warnings in the eastern part of the basin (ENP) that extends from the Pacific Coast of North America to 140°W, while NOAA's Central Pacific Hurricane Center in Honolulu, Hawaii, is responsible for issuing warnings in the central North Pacific (CNP) region between 140°W and the dateline. This section summarizes the TC activity in both warning areas using combined statistics, along with information specifically addressing the observed activity and impacts in the CNP region.

The ENP/CNP hurricane season officially spans from 15 May to 30 November. Hurricane and tropical storm activity in the eastern area of the basin typically peaks in September, while in the CNP TC activity normally reaches its seasonal peak in August (Blake et al. 2009). During the 2017 season, a total of 18 named storms formed in the combined ENP/CNP basin (Fig. 4.25a). This total includes 9 hurricanes, 4 of which were major hurricanes. The 1981–2010 IBTrACS seasonal averages for the basin are 16.5 named storms, 8.5 hurricanes, and 4.0 major hurricanes (Schreck et al. 2014).

The 2017 seasonal ACE index was 98.5 × 10^{4} kt^{2} (Fig. 4.25b), which is below the 1981–2010 mean of