while not at the named storm level of intensity. The North Atlantic hurricane season was below normal (section 4e2), and both the central and eastern Pacific hurricane seasons were well above normal (section 4e3), consistent with the El Niño conditions in place (section 4b). Sidebar 4.1 also provides analysis and a summary of the overall Northern Hemisphere TC seasons and highlights the special role that El Niño plays with respect to TCs. Sidebar 4.2 describes a rare and interesting subtropical cyclone that developed over the southeast Pacific, a region usually not conducive to such development.

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

(i) 2015 seasonal activity

The 2015 Atlantic hurricane season produced 11 named storms, of which four became hurricanes and two became major hurricanes. These values are not far below the HURDAT2 30-year (1981–2010) seasonal averages of 11.8 tropical storms, 6.4 hurricanes, and 2.7 major hurricanes (Landsea and Franklin 2013). Many of the storms during 2015 were weak and short-lived, and the seasonal accumulated cyclone energy (ACE) value (Bell et al. 2000) was 67.8% of the 1981–2010 median (92.4×10^4 kt^2; Fig. 4.19). This value is below NOAA's upper threshold (71.4% of the median) for a below-normal season (see www.cpc.ncep.noaa.gov/products/outlooks/background_information.shtml), and consequently the season is classified as below-normal.

A single storm, Major Hurricane Joaquin, produced nearly one-half of the season's total ACE value; the remaining ten storms produced an ACE value of only 36.1% of the median. This result highlights the large number of weak and short-lived storms during the season. Combined with a near-normal hurricane season in 2014 and a below-normal season in 2013 (Bell et al. 2015), 2013–15 marks the first time since 1992–94 in which three consecutive seasons were not above normal.

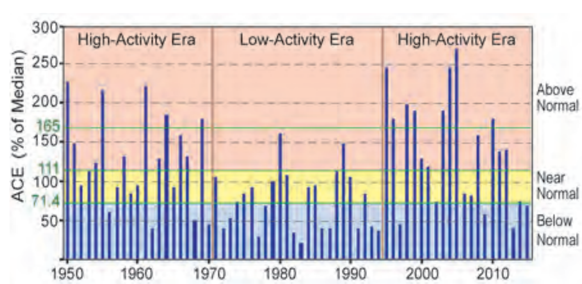

Fig. 4.19. NOAA's Accumulated Cyclone Energy (ACE) index expressed as percent of the 1981–2010 median value. ACE is calculated by summing the squares of the 6-hourly maximum sustained surface wind speed (knots) for all periods while the storm is at least tropical storm strength. Red, yellow, and blue shadings correspond to NOAA's classifications for above-, near- and below-normal seasons, respectively. The 165% threshold for a hyperactive season is indicated. Vertical brown lines separate high- and low-activity eras.

Since the current high-activity era for Atlantic hurricanes began in 1995, 13 of 21 seasons (62%) have been above normal, and four seasons (19%) have been near normal. The 2015 season marks only the fourth below-normal season since 1995. The 2015 activity was well below the averages during the recent active period (1995–2014) of 15 named storms, 7.6 hurricanes, 3.5 major hurricanes, and 141.6% of the 1981–2010 median ACE. A yearly archive of conditions during these seasons can be found in previous *State of the Climate* reports.

A main delineator between more- and less-active Atlantic hurricane seasons is the number of hurricanes and major hurricanes that originate as named storms within the Main Development Region (MDR; green boxed region in Fig. 4.20a) which spans 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). Only five named storms formed in the MDR during 2015, with two becoming hurricanes and one of those being a short-lived major hurricane. The resulting ACE value from these five storms was only about 27% of the median, which is comparable to the 1981–2010 below-normal season average for the MDR of 18.1%. These values are well below the above-normal and near-normal season ACE averages for the MDR of 151.1% and 57.9% of the median, respectively.

(ii) Storm tracks

Two tropical storms made landfall in the United States during 2015: Tropical Storm Ana which made landfall in South Carolina in May, and Tropical Storm Bill which made landfall in Texas in June. No hurricanes made landfall in the United States this season.

No hurricanes tracked through the Caribbean Sea during 2015. This region has seen only one hurricane in the last three seasons: Gonzalo in 2014. As discussed below, and also by Bell et al. (2014, 2015), this dearth of hurricane activity over the Caribbean Sea has reflected a lack of storms forming in the region due to strong vertical wind shear and anomalous sinking motion, and also a lack of storms propagating westward into the region.

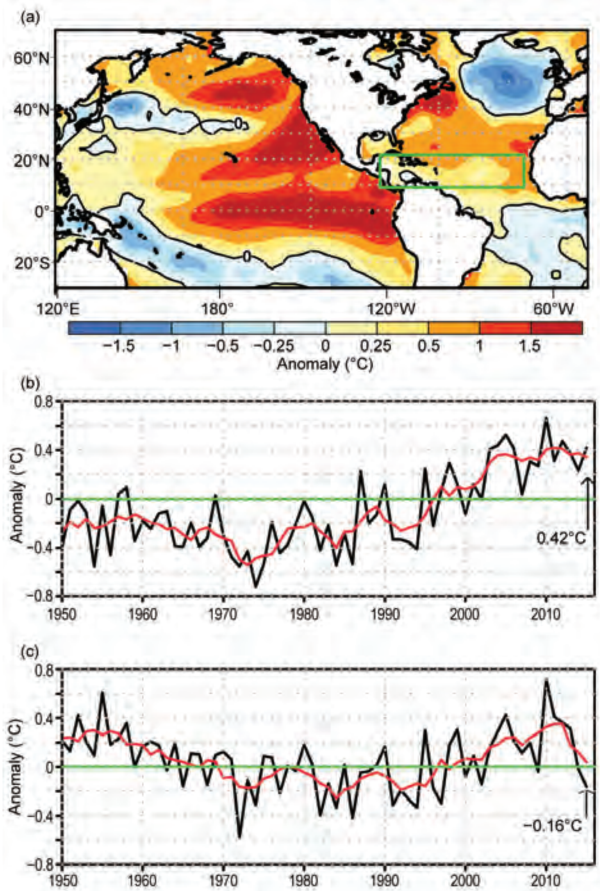

FIG. 4.20. (a) ASO 2015 SST anomalies (°C), with the MDR indicated by the green box. (b) Time series for 1950–2015 of ASO area-averaged SST anomalies in the MDR. (c) Time series showing the difference between ASO area-averaged SST anomalies in the MDR and those for the entire global tropics (20°N–20°S). Red lines show a 5-pt. running mean of each time series. Anomalies are departures from the ERSST.v3b (Smith et al. 2008) 1981–2010 period monthly means.

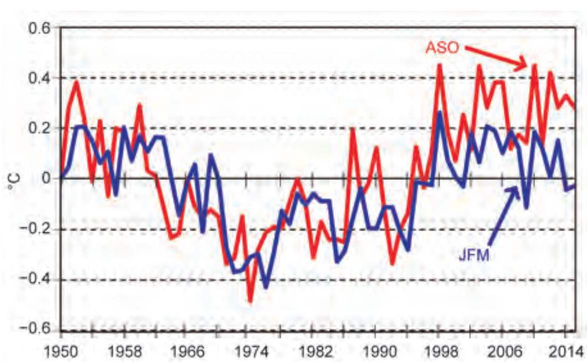

FIG. 4.21. Unfiltered index of the Atlantic multidecadal oscillation (AMO) during 1950–2015 averaged over ASO (red line) and JFM (blue line). Based on the Kaplan SST dataset (Enfield et al. 2001; www.esrl.noaa.gov /psd/data/timeseries/AMO).

(iii) Atlantic sea surface temperatures

SST anomalies warmed across the MDR as the summer progressed, with below-average SSTs during June–July and above-average SSTs during August–November. For the MDR as a whole, the area-averaged SST anomaly for October (+0.64°C) was the warmest in the 1950–2015 record, and the area-averaged anomaly for November (+0.48°C) tied for the warmest on record.

For the peak months (August–October, ASO) of the Atlantic hurricane season the mean SST departure in the MDR was +0.43°C (Fig. 4.20b), which ties for fifth warmest in the record (Fig. 4.20b). Consistent with the ongoing warmth in the MDR since 1995, objective measures of the Atlantic multidecadal oscillation (AMO; Enfield and Mestas-Nuñez 1999), such as NOAA's operational Kaplan AMO index, indicate a continuance of the AMO warm phase during ASO 2015 (Fig. 4.21). In contrast, the AMO index for January–March has been near zero for the past two years.

The warm AMO phase and the associated positive phase of the Atlantic Meridional Mode (Vimont and Kossin 2007; Kossin and Vimont 2007) are the primary climate factors associated with high-activity eras for Atlantic hurricanes (Goldenberg et al. 2001; Bell and Chelliah 2006; Bell et al. 2011, 2012). This warm phase features anomalously warm SSTs in the MDR compared to the remainder of the global tropics (Fig. 4.20c). However, the mean SST anomaly within the MDR during ASO 2015 was less than the mean anomaly for the entire global tropics, due partly to the intensifying El Niño (see section 4b).

(iv) Atmospheric conditions

a. Atlantic basin

The below-normal 2015 Atlantic hurricane season resulted mainly from a set of atmospheric conditions during ASO that made the central and western MDR extremely unfavorable for TC activity. These conditions included: 1) anomalously strong vertical wind shear extending from the Caribbean Sea northeastward to the central Atlantic (Fig. 4.22), 2) anomalous upper-level (200-hPa) convergence and lower-level (850-hPa) divergence (Fig. 4.23a), 3) anomalous sinking motion throughout the troposphere (Fig. 4.23b) and, 4) midlevel drier air (Fig. 4.23c).

The vertical wind shear averaged across the Caribbean Sea during ASO was the third strongest (12.4 m s^{-1}) in the ASO 1970–2015 record (Fig. 4.22b). The two ASO seasons with larger shear values in this region were the El Niño years of 1972 and 1986. For the June–November hurricane season as a whole, the vertical wind shear over the Caribbean Sea was

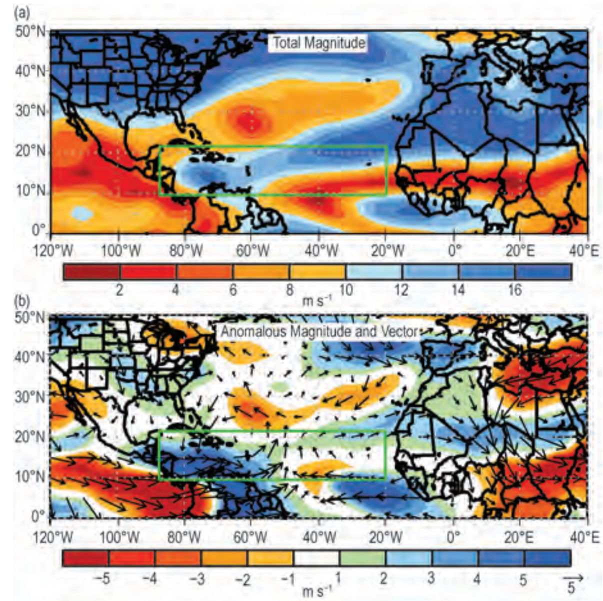

FIG. 4.22. 200–850 hPa vertical wind shear during ASO 2015: (a) magnitude (m s^{-1}) and (b) anomalous magnitude and vector. In (a), orange-red shading indicates areas where the vertical wind shear magnitude is ≤10 m s^{-1}. In (b), vector scale is below right of plot. Green box denotes the MDR. Anomalies are departures from the 1981–2010 means.

the strongest in the record (17.3 m s^{-1}), exceeding the previous largest value of 15.4 m s^{-1} recorded in 1972. On monthly time scales, shear values greater than 8–10 m s^{-1} are generally considered nonconducive to hurricane formation.

The main activity during the 2015 hurricane season reflected more conducive conditions over the eastern MDR and also over the western subtropical North Atlantic north of the MDR. In portions of the eastern MDR the combination of weak vertical wind shear (Fig. 4.22a), anomalous rising motion (Fig. 4.23b), and increased midlevel moisture (Fig. 4.23c) contributed to the development of five named storms, including two hurricanes. Over the western subtropical North Atlantic, a similar combination of conditions contributed to the development of five named storms north of the MDR. Two of these storms became hurricanes, with one becoming the only long-lived major hurricane of the season (Joaquin). Together, these five storms produced about 60% of the total seasonal ACE value.

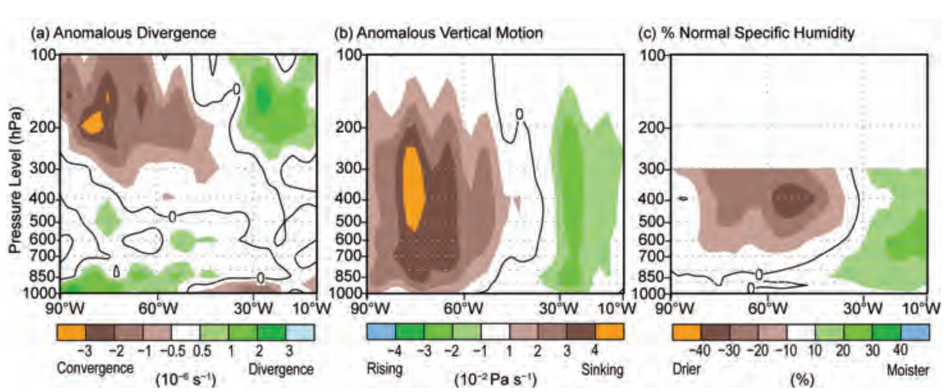

FIG. 4.23. ASO 2015: Atmospheric height–longitude sections averaged for 9.5°–21.5°N, of (a) anomalous divergence (× 10^{-6} s^{-1}), (b) anomalous vertical velocity (× 10^{-2} Pa s^{-1}), and (c) percent of normal specific humidity. Green shading indicates anomalous divergence, anomalous rising motion, and increased moisture, respectively. Brown shading indicates anomalous convergence, anomalous sinking motion, and decreased moisture. Zero lines are drawn on each panel. Anomalies are departures from the 1981–2010 means.

b. El Niño impacts

The 200-hPa circulation patterns during ASO 2015 (Fig. 4.24) show that El Niño impacted atmospheric conditions across the tropical Pacific and Atlantic Oceans in both hemispheres, so as to weaken the Atlantic hurricane season and simultaneously strengthen both the central and eastern Pacific hurricane seasons (see section 4e3).

The velocity potential, which is related to the divergent component of the wind, showed an anomaly pattern during ASO that is typical of El Niño (Fig. 4.24a). This pattern featured a core of negative anomalies across the eastern half of the Pacific basin, along with cores of positive anomalies over the western Pacific/Australasia and also over the Amazon basin and MDR. The associated pattern of divergent wind vectors shows a suppressive pattern for Atlantic hurricanes of anomalous upper-level convergence over the Caribbean Sea and central MDR.

The 200-hPa streamfunction pattern also showed a typical El Niño signal, with anticyclonic anomalies across the subtropical Pacific Ocean in both hemispheres flanking the region of enhanced El Niño–related convection (see Fig. 4.5c), along with cyclonic anomalies extending downstream from the Americas (Fig. 4.24b).

Regionally, the streamfunction pattern included an anomalous upper-level subtropical trough that extended across the entire MDR. This feature reflected an amplification of the mean tropical upper tropospheric trough (TUTT; white dashed line) in

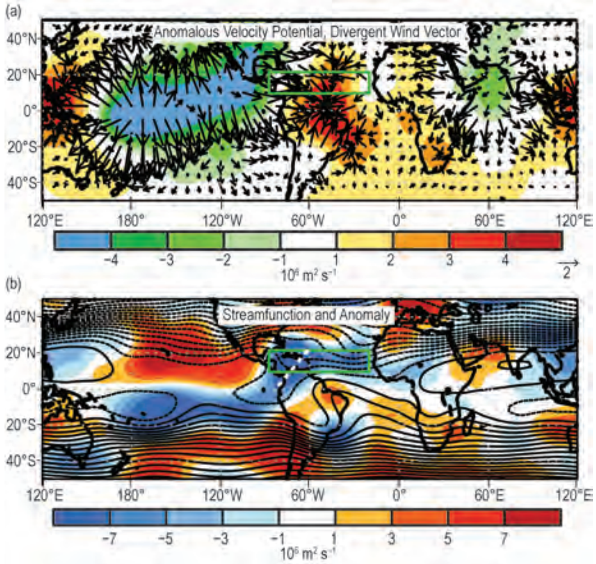

Fig. 4.24. 200-hPa circulation during ASO 2015: (a) anomalous velocity potential (× 10^6 m^2 s^{-1}) and anomalous divergent wind vector (m s^{-1}), and (b) total (contours) and anomalous (shaded) streamfunction (× 10^6 m^2 s^{-1}). Divergent wind vector scale in (a) is below right of plot. In (b), white dashed line indicates amplified tropical upper tropospheric trough (TUTT). Anticyclonic anomalies are indicated by positive values (orange/red) in the NH and negative values (blue) in the SH. Cyclonic anomalies are indicated by negative values in the NH and positive values in the SH. Green boxes indicate the Atlantic hurricane MDR. Anomalies are based on the 1981–2010 climatology.

the western MDR and a disappearance of the mean upper-level subtropical ridge normally located over the central and eastern MDR. These conditions contributed anomalous upper-level westerly winds, increased vertical wind shear, and anomalous sinking motion across the MDR (Figs. 4.22, 4.23), the combination of which suppressed the 2015 Atlantic hurricane season.

3) Eastern North Pacific and central North Pacific basins—M. C. Kruk, C. J. Schreck, and T. Evans

(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 date line. 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 central Pacific, TC activity normally reaches its seasonal peak in August (Blake et al. 2009). During the 2015 season, a total of 26 named storms formed in the combined ENP/CNP basin. This total included 16 hurricanes, 11 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 2015 season's 26 named storms is the highest storm count since the 1992 season. In late August, Hurricanes Kilo, Ignacio, and Jimena reached Category 4 status at the same time (Fig. SB4.1a). This was the first time on record that three Category 4 or stronger TCs were present at the same time in any global TC basin.

Given that 68% of the ENP/CP hurricanes in 2015 reached major hurricane status, it is no surprise that

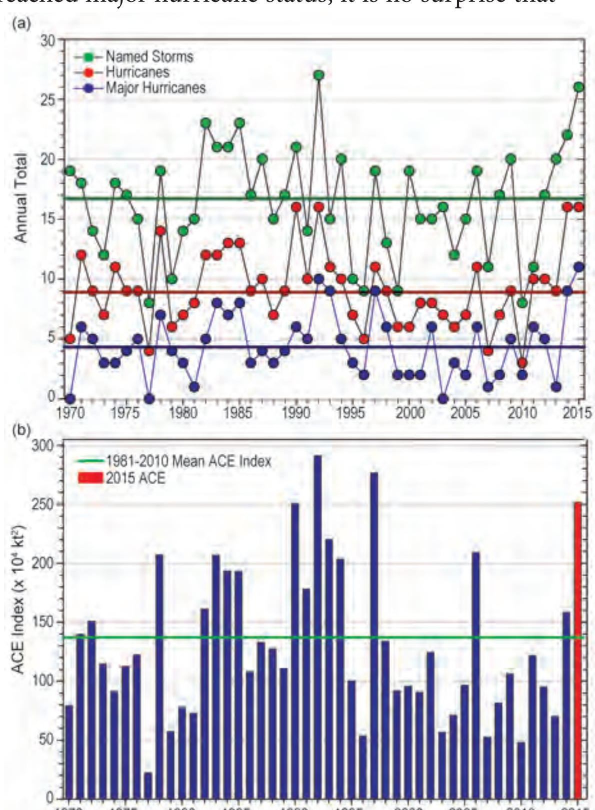

Fig. 4.25. Seasonal TC statistics for the full ENP/CNP basin over the period 1970–2015: (a) number of named storms, hurricanes, and major hurricanes, and (b) the ACE index (× 10^4 kt^2) with the 2015 seasonal total highlighted in red. The time series shown includes the corresponding 1981–2010 base period means for each parameter.