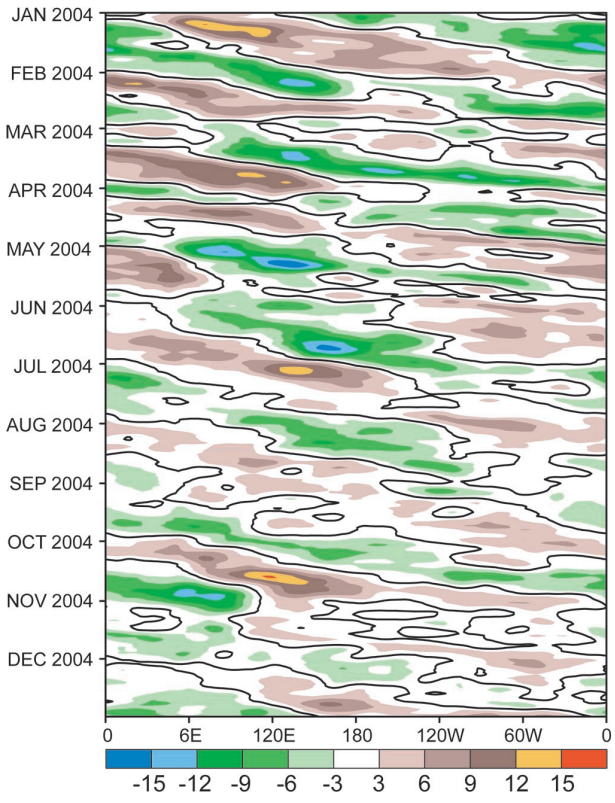

Fig. 4.4. Time–longitude section (5°N–5°S) of daily 200-hPa velocity potential anomalies during 2004. The shading interval is 3 × 10^6 m^2 s^{-1}, and the thick solid contour is the zero line. Anomalies were determined as departures from the 1971–2000 base period daily means, and plotted using a 5-day running mean smoother.

and North America. During May, these conditions contributed to one of the strongest negative phases of the Pacific–North American (PNA) teleconnection pattern on record for that month. Key aspects of this pattern included above-average 500-hPa heights over the Gulf of Alaska and southern United States, and below-average heights over the central subtropical North Pacific and Canada. This circulation brought a strong northwesterly flow of arctic air from Alaska and the Beaufort Sea into western Canada in the area downstream of the mean upper-level ridge axis, and led to near-record cold surface temperatures (2°–5°C below average) across most of that country (see section 6a1).

b. Tropical storms

1) Atlantic hurricane season—G. D. Bell,[4] S. Goldenberg,[20] C. Landsea,[20] E. Blake,[6] R. Pasch,[6] M. Chelliah,[4] and K. Mo[4]

(i) *Overview*

The 2004 Atlantic hurricane season had well above-normal activity, with 15 named storms,[4.1] 9 hurricanes (Hs), and 6 major hurricanes (MHs; defined as categories 3–5 on the Saffir–Simpson scale; Simpson 1974). Nine of these systems struck the continental United States—three as tropical storms and six as hurricanes. Three of the hurricanes hit the United States as major hurricanes.

Five named storms hit Florida in 2004—one as a tropical storm (Bonnie) and four as hurricanes (Charley, Frances, Ivan, and Jeanne). This tied the record with Texas (in 1886) for the most hurricanes to hit one state in a single season. Also, all three landfalling major hurricanes struck Florida, which was the most ever recorded for that state in a single season since accurate records began in 1900.

(ii) *2004 seasonal activity*

One measure of seasonal activity is NOAA's Accumulated Cyclone Energy (ACE) Index (Bell et al. 2000), which accounts for the combined strength and duration of tropical storms and hurricanes during a given season. This wind energy index is calculated by summing the squares of the 6-h maximum sustained surface wind speed in knots ($\Sigma\, V\mathrm{max}^2$) for all periods while the system is either a tropical storm or hurricane. The total ACE Index value for the 2004 season was 257% of the 1951–2000 median (Fig. 4.5), which was the third-largest seasonal value in the 1950–2004 record, exceeded only by 1950 and 1995.

During above-normal Atlantic hurricane seasons, a large fraction of the total ACE value results from tropical storms that form in the main development region (MDR; which consists of the tropical Atlantic and Caribbean Sea south of 21.5°N), and later develop into hurricanes and major hurricanes (Goldenberg and Shapiro 1996). During 2004, nine tropical storms formed in the MDR, with seven subsequently intensifying into hurricanes. These systems accounted for 92% of the total ACE value. Major Hurricane Ivan, the strongest hurricane of the season, which eventually made landfall in Alabama and brought hurricane-force winds to the western Florida Panhandle, produced the largest storm total ACE value (70.4×10^4 kt^2) in the reliable record dating back to 1944.

The 2004 hurricane season was a continuation of a series of above-normal seasons that began in 1995 (Goldenberg et al. 2001), in response to favorable atmospheric and oceanic conditions in the MDR.

[4.1] Note that Nicole, which developed in October, was officially categorized as a "subtropical" cyclone by NOAA's National Hurricane Center (NHC).

During 1995–2004, Atlantic hurricane seasons have averaged 13.6 TSs, 7.8 Hs, and 3.8 MHs, with an ACE value of 169% of the median, and with above-normal activity in every season except for the two El Niño years of 1997 and 2002. In contrast, seasons during the below-normal 24-yr period of 1971–94 averaged only 8.6 TSs, 5.0 Hs, and 1.5 MHs, with an ACE value of 75% of the median, and included only three seasons that were above normal (1980, 1988, 1989).

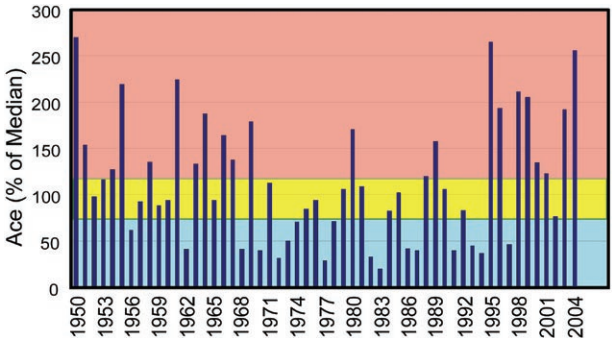

Fig. 4.5. Atlantic hurricane season values of the NOAA ACE Index expressed as percent of the 1951–2000 median value. NOAA definitions of season types are indicated by the background shading, with pink, yellow, and blue indicating above-, near-, and below-normal seasons, respectively.

(iii) *Landfalling U.S. tropical systems and associated rainfall*

During 2004, three of the systems that struck the United States hit as tropical storms (Bonnie, Hermine, and Matthew), three struck as category 1–2 hurricanes (Alex, Gaston, and Frances), and three hit as major hurricanes (Charley, Ivan, and Jeanne). The first eight strikes,[4.2] including all five in Florida, occurred during August and September. For this 2-month period, rainfall from Florida to Pennsylvania was 200% or more of average, mainly due to the landfalling storms. The total rainfall associated with these systems reached 500 mm or more across Florida, Georgia, and the western Carolinas (not shown), and accounted for 60%–80% of the 2-month total in these regions.

Rainfall totals for each of the nine named storms that struck the United States are summarized in Fig. 4.6. Three of these hurricanes with long tracks over the eastern United States produced the largest precipitation totals. The first of these was H Frances during 5–9 September, which brought more than 175 mm of rain to Florida, Georgia, and the western Carolinas (Fig. 4.6f). The second was MH Ivan during 16–18 September, which produced more than 150 mm

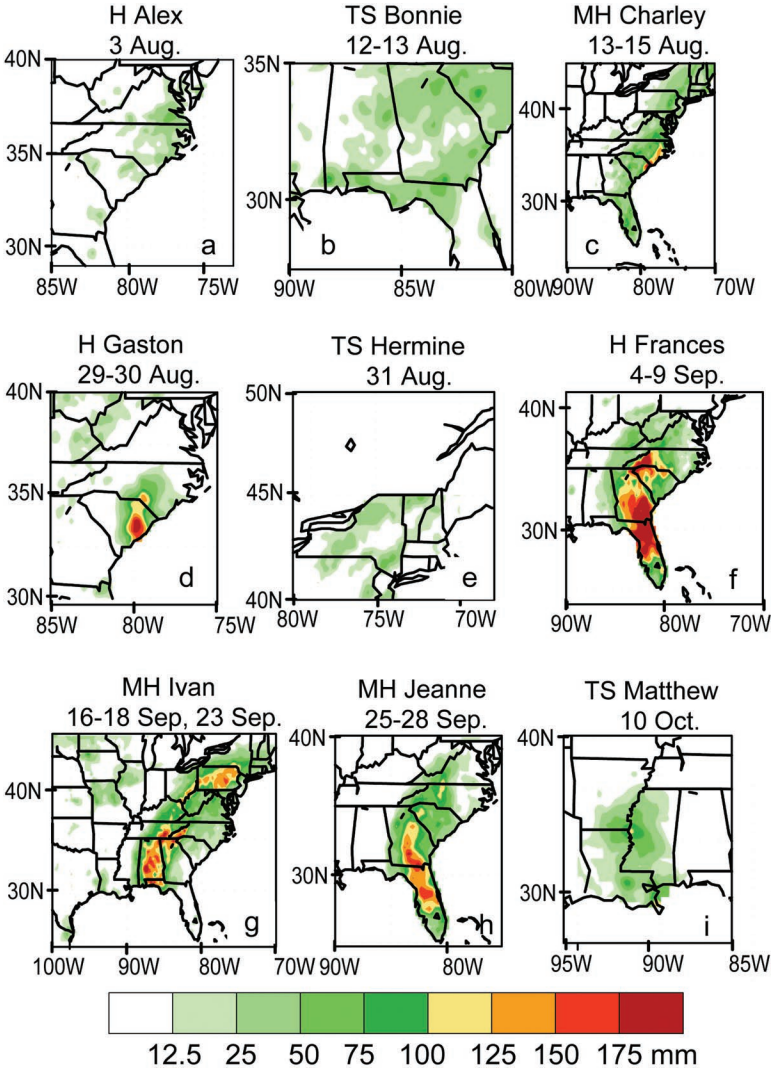

Fig. 4.6. Storm total rainfall amounts (mm) for the nine tropical systems that struck the United States during 2004: (a) Alex, (b) Bonnie, (c) Charley, (d) Gaston, (e) Hermine, (f) Frances, (g)Ivan, (h) Jeanne, and (i) Matthew.

[4.2] According to NOAA/NHC, a hurricane strike occurs if that location passes within the hurricane's strike circle, a circle of 125 n mi in diameter, centered 12.5 n mi to the right of the hurricane center (i.e. in the direction of motion). Therefore, a strike is different than a landfall, which is the intersection of the surface center of a tropical cyclone with a coastline.

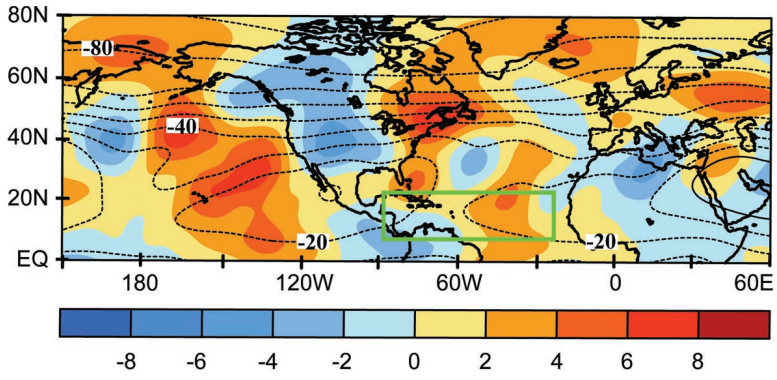

Fig. 4.7. 200-hpa streamfunction (contours, interval is 10×10^6 m^2 s^{-1}) and anomalies (shading) during Aug–Sep 2004. Anticyclonic (cyclonic) anomalies are indicated by positive (negative) values. The green box denotes the MDR, with anomalies determined as departures from the 1971–2000 base period monthly means.

of rain from Alabama to Pennsylvania (Fig. 4.6g). Ivan eventually tracked to the southwest, and back into the Gulf of Mexico, where it regained tropical storm status before making a second landfall on 23 September in southeastern Texas. The third was MH Jeanne during 25–28 September, which produced 100+ mm rainfall totals from Florida to the western Carolinas (Fig. 4.6h).

All but one of the nine named storms (Alex) that struck the United States during 2004 officially made landfall. Since 2002, the United States has experienced 19 landfalling named storms, with seven occurring in 2002 and four in 2003 (Bell et al. 2003; Bell et al. 2004; Pasch et al. 2004; Lawrence et al. 2005). Eleven of these 19 systems hit as tropical storms and eight hit as hurricanes. The Gulf Coast region from the southern tip of Texas to the southern tip of Florida has been struck by 12 of these named storms (5 in 2002, 3 in 2003, and 4 in 2004), with 8 hitting as tropical storms and 4 as hurricanes.

(iv) *Atmospheric and oceanic conditions*

Almost all of the 2004 seasonal activity occurred during August and September, and the mean atmospheric and oceanic conditions during this period were characteristic of most above-normal seasons. At middle and upper levels, the subtropical ridge was stronger than average from the Gulf of Mexico to northern Senegal (Fig. 4.7), with large anticyclonic anomalies that extended northward along the U.S. east coast. South of the mean ridge axis, anomalous upper-level easterly flow covered the entire MDR (not shown). Over the eastern North Atlantic and western Africa, these conditions are consistent with the ongoing active Atlantic multidecadal signal (Bell et al. 2004). Over the western subtropical North Atlantic and eastern United States they were linked to a large-scale pattern of extratropical circulation anomalies that had previously persisted from April through July.

The pronounced westward extent of the enhanced subtropical ridge and anomalous upper-level easterlies contributed to below-average vertical wind shear across the MDR during August–September (Fig. 4.8), which aided in the formation of intense and long-lived hurricanes. The mean steering current during September 2004, characterized by a 500-hPa ridge along the U.S. east coast, caused the systems to track further west than normal, eventually making landfall in Florida and the Gulf Coast region. Several of these systems were then steered over the eastern United States, producing heavy rains and flooding along their paths. These conditions were in marked contrast to the climatological mean (not shown), which features a broad trough across the eastern United States that acts to divert (i.e., recurve) hurricanes out to sea, often well prior to reaching the U.S. east coast.

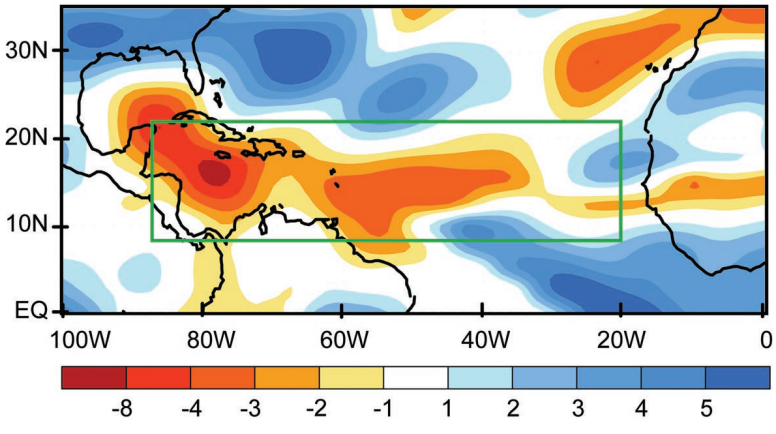

Fig. 4.8. Anomalous magnitude of the 200–850-hPa vertical wind shear (m s^{-1}) during Aug–Sep 2004. Yellow–red and blue shading indicates below-average and above-average wind shear magnitudes, respectively. The green box denotes the MDR, with anomalies determined as departures from the 1971–2000 base period monthly means.

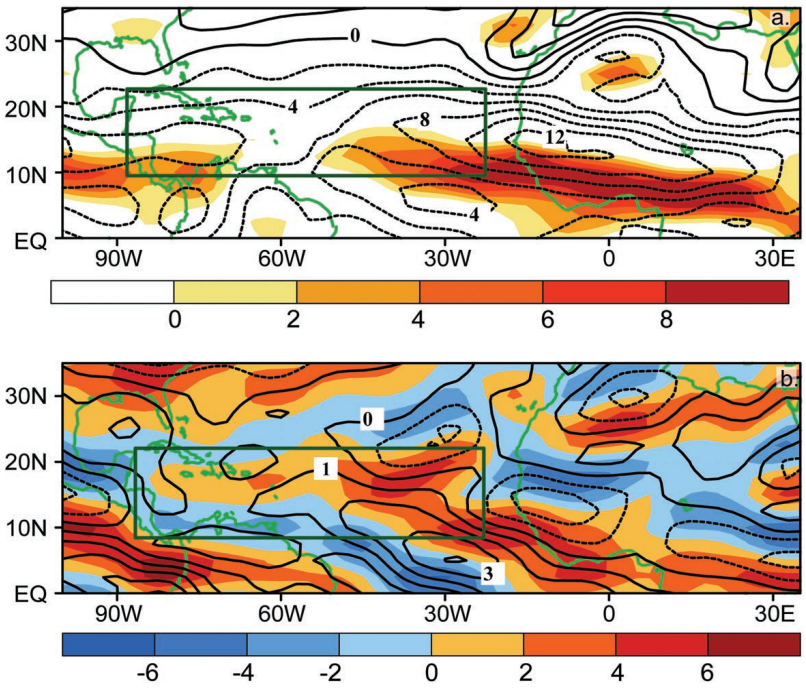

Fig. 4.9. 700-hPa zonal winds (contours) and relative vorticity (shading) during Aug–Sep 2004: (a) mean and (b) anomalies. The contour interval for winds is 1.0 m s^{-1}, and for vorticity is 1 × 10^{-6} s^{-1}. In (a), only cyclonic relative vorticity values are shaded. In (b), cyclonic anomalies are shaded yellow–red and anticyclonic anomalies are shaded blue. The green box in both panels denotes the MDR, with anomalies determined as departures from the 1971–2000 base period monthly means.

In the lower atmosphere, the 700-hPa African easterly jet (AEJ) was well defined during August–September, and its associated region of strong cyclonic vorticity extended farther west than normal into the central MDR (Fig. 4.9a). These conditions were associated with a below-average strength of the tropical easterly trade winds, as indicated by westerly anomalies from the eastern Pacific to western Africa (Fig. 4.9b). The 2004 hurricane season also featured exceptionally warm (0.5°–1.25°C above average) SSTs in the central MDR. For the entire MDR, area-averaged SSTs during August–September were almost two standard deviations above normal—the second warmest since 1950 (Fig. 4.10).

The conditions described above indicate that the African easterly waves during the peak of the season were embedded within an extended region of increased cyclonic vorticity along the equatorward flank of the AEJ as they moved westward over very warm SSTs into the low-shear environment of the central and western MDR. This combination of conditions is known to favor very active hurricane seasons. These conditions are also key ingredients of the active Atlantic multidecadal signal that has prevailed since 1995 (Landsea et al. 1999; Mestas-Nuñez and Enfield 1999; Goldenberg et al. 2001; Bell et al. 2004).

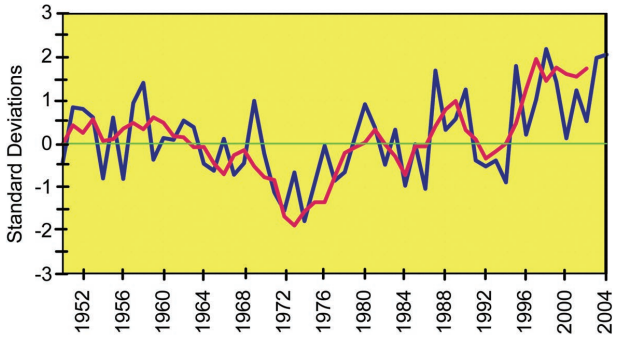

Fig. 4.10. Aug–Sep area-averaged, standardized SST anomalies (blue) in the MDR during 1950–2004. The standardized 5-yr running mean of Aug–Sep anomalies is shown in red. The analysis is based on the extended reconstructed SST dataset of Smith and Reynolds (2004), with anomalies determined as departures from the 1971–2000 base period monthly means.

ii) North Pacific tropical storms

(i) *Western North Pacific typhoon season*—S. J. Camargo[5]

The 2004 western North Pacific typhoon season was an active one, with 32 tropical cyclones [tropical depressions (TDs), tropical storms (TSs), and typhoons (TYs)], which was slightly above the 1971–2000 climatological median of 30.5 (JTWC 2005). All but two of the tropical cyclones in 2004 (i.e., TD Malou and TD Haima) reached tropical storm intensity or higher.[4.3] Figure 4.12a shows the number of tropical cyclones reaching at least tropical storm strength each year since 1945. There were 30 named storms (NSs)[4.4] in 2004 (9 TSs and 21 TYs),

[4.3] In contrast to the JTWC data, the Japan Meteorological Agency (JMA) categorized Malou as a tropical storm, with winds ~40 kt during landfall at 1300 UTC 4 August 2004.

[4.4] Named storms include all tropical cyclones that reach at least tropical storm intensity (34 kt or greater), that is, TS and TY.