3.3 Case studies

3.3.1 17 February 2006

3.3.1.1 Overview

The 17 February 2006 hybrid high-wind event was chosen for analysis because it was a high impact event, it was a challenge to forecast, and it illustrates mechanisms associated with high winds in addition to mechanisms that were represented in the composite analysis. Two people were fatally injured in Irondequoit, NY, and Saratoga Springs, NY, as a result of fallen trees due to high winds during this event. This hybrid event produced 267 high-wind reports in the NE (and $3.5 million in damage in New York State alone), the most high-wind reports produced by any cool-season high-wind event that impacted the NE from 15 October 1993 through 31 December 2008. The 267 high-wind reports in the NE consisted of 242 gradient-wind reports and 25 thunderstorm-wind reports (Fig. 3.23a). The most noteworthy high-wind report was a measured bow echo-related 85 kt thunderstorm-wind gust measured at the Saratoga County (NY) Airport at 1500 UTC (Fig. 3.23b). The initial NE report occurred in the southeast quadrant of a surface cyclone at 0900 UTC 17 February; therefore 0600 UTC 17 February is the GFS analysis time that corresponds to t = 00 h.

3.3.1.2 Synoptic overview

The 17 February hybrid event was associated with a surface cyclone that developed near the panhandle of Texas at t = −24 h and moved rapidly northeast through southern Ontario at t = 00 h and southern Quebec at t = +12 h (Fig. 3.24). Like the hybrid southeast composite cyclone track, the surface cyclone track for the 17 February
event was northeastward, passing through southern Canada (Fig. 3.24). This surface cyclone strengthened as it progressed northeastward, experiencing a maximum deepening rate of 7 hPa (6 h)$^{-1}$ from $t = +12$ h to $t = +18$ h (Fig. 3.24). At 0600 UTC 17 February ($t = 00$ h), this surface cyclone was located in southeastern Ontario (Fig. 3.25a). The initial NE report was located along an axis of high precipitable water that was drawn poleward from the Gulf of Mexico ahead of an eastward-moving cold front (Fig. 3.25a). At $t = 00$ h, the 12-h centered MSLP falls and rises were approximately $-24$ and $24$ hPa ($12$ h)$^{-1}$, respectively, with the initial NE report occurring where the isallobaric gradient was strong (Fig. 3.25b). The 1000-hPa isallobaric wind was approximately 20 kt in the vicinity of the initial NE report (Fig. 3.25b). The 850-hPa temperature was approximately 8°C, and the winds were southwesterly near 70 kt in the vicinity of the initial NE report (Fig. 3.25c). Strong cold advection was occurring west of the initial NE report at 850 hPa (as implied from the magnitude and orientation of the winds relative to the isotherms in the vicinity of the initial NE report; Fig. 3.25c). At 700 hPa, the initial NE report occurred in a region of ascent and high relative humidity (Fig. 3.25d). A region of dry air was located west of the initial NE report behind the leading edge of the cold front (Figs. 3.25c,d). The surface cyclone and initial NE report occurred downstream of a 500-hPa short-wave trough (Fig. 3.25e) and a 160 kt 300-hPa jet streak (Fig. 3.25f). The surface cyclone center was located beneath a region of divergence at 300 hPa (Figs. 3.25a,f), which is favorable for cyclogenesis and strengthening low-level wind speeds.
3.3.1.3 Identification of high winds

According to radar imagery and surface observations at 1200 UTC 17 February, a cold-frontal rainband was observed in central Pennsylvania, west of a prefrontal rainband (Fig. 3.26a). A temperature drop of 8°C and a wind shift from southwesterly to northwesterly was observed across the cold-frontal rainband in central Pennsylvania (Fig. 3.26a). Wind gusts greater than 40 kt were observed west of the cold-frontal rainband, with Rochester, NY, experiencing a wind gust of 57 kt (Fig. 3.26a). Severe gradient winds at 1200 UTC were reported west of, along, and east of the cold-frontal rainband (Fig. 3.26b).

At 1500 UTC, the northern portion of the cold-frontal rainband developed multiple bowing segments characteristic of bow echoes (Fig. 3.26c). Wind gusts in excess of 40 kt persisted west of the cold-frontal rainband from 1200 to 1500 UTC, with the cities of Syracuse, NY, and Watertown, NY, experiencing wind gusts greater than 50 kt (Fig. 3.26c). In addition to the observed wind gusts behind the cold front, 40 kt wind gusts were observed in eastern Massachusetts, east of the prefrontal rainband (Fig. 3.26c). Severe thunderstorm winds and lightning flashes were reported along the cold-frontal rainband, specifically near the apices of the bowing segments (Fig. 3.26d). It is likely that downdrafts associated with these bowing segments aided in downward transport of high momentum air to the surface. Severe gradient winds were reported behind the cold front and farther east in eastern Massachusetts (Fig. 3.26d).

At 1800 UTC, wind gusts in excess of 40 kt occurred along and behind the cold-frontal rainband (Fig. 3.26e). Severe gradient winds were reported along and behind the cold-frontal rainband as well as east of the prefrontal rainband in Maine (Fig. 3.26f).
Lightning flashes were reported along the northern portion of the cold-frontal rainband in western Maine (Fig. 3.26f).

3.3.1.4 Diagnosis of high winds

Radar imagery from 1200, 1500, and 1800 UTC on 17 February indicates that thunderstorms formed along a cold front and became organized into high wind-producing bow echoes. At 1200 UTC, CAPE values from the $1^\circ \times 1^\circ$ GFS analyses were between 5 and 20 J kg$^{-1}$ in the vicinity of the cold-frontal rainband (Figs. 3.26a and 3.27a). The 1000–500-hPa shear values in the vicinity of the cold-frontal rainband were greater than 75 kt and as high as 100 kt in other areas of the NE (Figs. 3.26a and 3.27a). At 1800 UTC, three hours after the 85 kt wind gust was measured at Saratoga County Airport, CAPE values increased to between 25 and 50 J kg$^{-1}$ in the vicinity of the cold-frontal rainband (Figs. 3.26e and 3.27b). The 1000–500-hPa shear values were near 90 kt in the vicinity of the cold-frontal rainband in eastern Massachusetts (Figs. 3.26e and 3.27b).

At 1200 UTC, an intrusion of dry, high potential vorticity (PV) air was present above the cold front (Fig. 3.28a). Negative equivalent potential temperature advection was occurring throughout the troposphere in the vicinity of the cold front (Fig. 3.28b). In concert with an intrusion of dry air (Fig. 3.28a), upward-decreasing equivalent potential temperature advection acted to develop a layer of potentially unstable air at the leading edge of the cold front between 850 and 700 hPa (Fig. 3.28b). Ascent, likely associated with frontogenesis, was occurring on the warm side of the cold front in the vicinity of the layer of potential instability (Figs. 3.28b,c). Ascent in the presence of potential instability is conducive to the development of thunderstorms and thunderstorm-related
downdrafts. Subsidence was occurring in the vicinity of the dry-air intrusion (Figs. 3.28a,c). The cold front was characterized by vertically oriented isentropes from the surface to above 850 hPa, indicating that the planetary boundary layer (PBL) was deep and characterized by lapse rates that were approximately dry adiabatic (Figs. 3.28a–d). Wind speeds at 850 hPa behind and at the leading edge of the cold front were 55 and 45 kt, respectively (Fig. 3.28d). Steep lapse rates from the surface to above 850 hPa in the presence PBL wind speeds in excess of 40 kt likely promoted turbulent transport of high momentum air to the surface.

At 1800 UTC, dry air penetrates farther downward into the troposphere into the top of the PBL (Fig. 3.29a). Beneath the dry-air intrusion the PBL became drier from 1200 UTC to 1800 UTC, which suggests the air associated with the dry intrusion was mixed downward into the PBL (Fig. 3.29a). Tropospheric-deep negative equivalent potential temperature advection occurred with regions of potential instability located at the leading edge of the cold front (Fig. 3.29b). Although frontogenesis continued to occur at the leading edge of the cold front, the magnitude of the frontogenesis decreased from between 10 and 12 K (100 km)$^{-1}$ (3 h)$^{-1}$ at 1200 UTC to between 2 and 4 K (100 km)$^{-1}$ (3 h)$^{-1}$ at 1800 UTC (Fig. 3.29c). Lapse rates from the surface to above 850 hPa were approximately dry adiabatic within and behind the cold front (Figs. 3.29a–d). Subsidence occurred behind the cold front (Fig. 3.29d). Wind speeds at 850 hPa within the cold front were as high as 55 kt (Fig. 3.29d). As was the case at 1200 UTC, steep lapse rates from the surface to above 850 hPa in the presence of near 55 kt winds at 850 hPa likely promoted turbulent transport of high momentum air to the surface.
3.3.1.5 Summary

In association with a cold-frontal passage, two high-wind regimes occurred during the 17 February 2006 hybrid high-wind event. A surface cyclone moved rapidly northeastward through southern Canada and deepened by as much as 7 hPa (6 h)$^{-1}$, which led to a strong isallobaric gradient and 20 kt isallobaric winds in the vicinity of high-wind reports. Severe thunderstorms developed in an environment characterized by ascent, likely associated with frontogenesis, in the presence of potentially unstable layers along a cold front. In the presence of high 1000–500-hPa shear values, a cold-frontal rainband became organized into high wind-producing bowing segments as evident in the radar imagery. Downdrafts associated with these bowing segments likely promoted transport of high momentum air to the surface, as thunderstorm-wind reports occurred near the apices of these bowing segments. During and after the cold-frontal passage, strong tropospheric-deep negative equivalent potential temperature advection and subsidence occurred where dry, high-momentum air penetrated into the PBL. The PBL was characterized by approximately dry-adiabatic lapse rates and wind speeds in excess of 40 kt, which likely promoted turbulent transport of high momentum air to the surface.

3.3.2 15 April 2007

3.3.2.1 Overview

The 15–16 April 2007 high-wind event was chosen for farther analysis because it was a high-impact event. The 15–16 April event was associated with gradient-wind reports that occurred in the northeast, northwest, and southwest quadrants of a surface cyclone. This event was considered a hybrid event because a lightning flash report
occurred within 1° radial distance and 1 h of a gradient-wind report. The 15–16 April event produced 76 gradient-wind reports in the NE and was associated with 115 lightning flash reports that occurred between 81°W and 65°W and between 38°N and 48°N (Fig. 3.30). The initial NE report occurred in the northeast quadrant of a surface cyclone at 1745 UTC 15 April; therefore 1800 UTC 15 April is the GFS analysis time that corresponds to t = 00 h.

3.3.2.2 Synoptic overview

The 15–16 April event was associated with a surface cyclone that developed on the border of Texas and Louisiana at 0600 UTC 14 April, 36 h prior to the initial NE report. After moving over the Appalachian Mountains, the 15–16 April surface cyclone center was located in eastern North Carolina at 1800 UTC 15 April (t = 00 h; Fig. 3.31). Despite the 15–16 April event being a hybrid event, the surface cyclone track associated with the 15–16 April event is consistent with the pure gradient northeast composite surface cyclone track in that the 15–16 April surface cyclone tracked from southwest to northeast along the Atlantic Coast (Fig. 3.31). The 15–16 April surface cyclone strengthened as it progressed northeastward, experiencing a maximum deepening rate of 9 hPa (6 h)^{-1} from t = +06 h to t = +12 h (Fig. 3.31). According to the 1° × 1° GFS analyses, the surface cyclone reached its peak intensity at 1200 UTC 16 April over Long Island, NY with a minimum MSLP of 972 hPa (Fig. 3.31). A measured MSLP minimum of 969 hPa was reported at 1200 UTC 16 April in the hourly surface observations taken on Long Island, NY (not shown).
At 1800 UTC 15 April (t = 00 h), the 15–16 April surface cyclone was located in eastern North Carolina (Fig. 3.32a). The initial NE report occurred in the northeast quadrant of this surface cyclone along an axis of warm, moist air that was drawn poleward from the Atlantic Ocean (Fig. 3.32a). The initial NE report occurs where precipitable water values were between 28 and 32 mm (Fig. 3.32a). The 12-h centered MSLP falls and rises were approximately −20 and 8 hPa (12 h)\(^{-1}\), respectively, with the initial NE report occurring near the isallobaric minimum (Fig. 3.32b). The 1000-hPa isallobaric wind was approximately 10 kt in the vicinity of the initial NE report (Fig. 3.32b). The 850-hPa temperature was approximately 4°C and the wind was southerly at approximately 50 kt in the vicinity of the initial NE report (Fig. 3.32c). Warm advection was occurring in the vicinity of the initial NE report at 850 hPa (Fig. 3.32c). At 700 hPa, the initial NE report occurred in a region of ascent and high relative humidity (Fig. 3.32d). The initial NE report occurred southeastward of a 500-hPa cutoff cyclone center (Fig. 3.32e). The 15–16 April surface cyclone center was located beneath the poleward exit region of a 120 kt 300-hPa jet streak (Figs. 3.32a,f), a region generally favorable for deep ascent and cyclogenesis.

At 0600 UTC 16 April (t = +12 h), the 15–16 April surface cyclone deepened to 976 hPa and moved off the coast of New Jersey (Fig. 3.33a). Severe gradient-winds were reported in the northeast quadrant of the surface cyclone along an axis of warm, moist air where precipitable water values were between 24 and 32 mm (Fig. 3.33a). The 1000-hPa wind speeds in the vicinity of the gradient-wind reports were near 35 kt (Fig. 3.33a). The 12-h centered MSLP falls and rises were −24 and 12 hPa (12 h)\(^{-1}\), respectively, with gradient-wind reports occurring near the isallobaric minimum (Fig. 3.33b). The 1000-
hPa isallobaric wind was approximately 10 kt in the vicinity of the gradient-wind reports (Fig. 3.33b). Warm advection was occurring in the vicinity of the gradient-wind reports at 850 hPa (Fig. 3.33c). A region of strong baroclinicity at 850 hPa was located on the west side of the 15–16 April surface cyclone center (Figs. 3.33a,c). At 700 hPa, a dry-air intrusion was present separating a region of ascent associated with the cold front at 850 hPa (Figs. 3.33c,d) and a region of ascent associated with the region of strong baroclinicity on the west side of the surface cyclone center (Figs. 3.33a,c,d). The 500-hPa cutoff cyclone present at 1800 UTC 15 April moved over Delaware by 0600 UTC 16 April (Fig. 3.33e). The surface cyclone center at 0600 UTC 16 April was located slightly downstream of the 500-hPa cutoff cyclone (Figs. 3.33a,e) beneath the poleward jet-exit region of a 300-hPa jet streak (Figs. 3.33a,f).

At 1200 UTC 16 April (t = +18 h), the surface cyclone deepened to 972 hPa and moved over Long Island, NY (Fig. 3.34a). As was the case at 0600 UTC 16 April, severe gradient-winds were reported in the northeast quadrant of the surface cyclone (Fig. 3.34a). The severe gradient-wind reports occurred along an axis of warm, moist air where precipitable water values were between 16 and 24 mm (Fig. 3.34a). The 12-h centered MSLP falls and rises were −12 and 8 hPa (12 h)$^{-1}$, respectively (Fig. 3.34b). At 850 hPa, a region of cold air wrapped cyclonically around south of the 15–16 April surface cyclone center (Fig. 3.34c). The region of dry air at 700 hPa at 1200 UTC 16 April (Fig. 3.34d) was located farther east compared to 0600 UTC 16 April (Fig. 3.33d). The 500-hPa cutoff cyclone center was located directly above the 15–16 April surface cyclone center (Figs. 3.34a,e), which is an indication that the 15–16 April surface cyclone had reached its peak intensity. The 15–16 April surface cyclone center was located
beneath the poleward jet-exit region of a 300-hPa jet streak (Figs. 3.34a,f) that weakened from 140 kt at 0600 UTC to 120 kt at 1200 UTC (Figs. 3.33f and 3.34f).

3.3.2.3 Identification of high winds

At 0300 UTC 16 April, southeasterly wind gusts in excess of 40 kt occurred along the Atlantic coast in Massachusetts and Rhode Island in the northeast quadrant of the 15–16 April surface cyclone (Fig. 3.35a). A 42 kt wind gust was observed on Long Island, NY, at 0300 UTC 16 April (Fig. 3.35a). Lightning flashes were reported in proximity to and within 20 min of the 42 kt wind gust observed on Long Island, NY (Fig. 3.35a). Wind gusts in excess of 40 kt were also observed along the eastern slopes of the Appalachian Mountains (Fig. 3.35a).

At 0600 UTC 16 April, severe gradient-wind reports occurred in Maine, New Hampshire, and Rhode Island (Fig. 3.35b). Wind gusts in excess of 40 kt were reported along the Atlantic coast in Massachusetts, as well as in the southwest quadrant of the surface cyclone in Delaware, Maryland, and Virginia (Fig. 3.35b). A lightning flash was reported in Delaware in proximity to radar echoes exceeding 50 dBZ and a 41 kt observed wind gust (Fig. 3.35b).

At 0800 UTC 16 April, severe gradient winds and wind gusts in excess of 40 kt continued to be reported and observed, respectively, along the Atlantic coast in the northeast quadrant of the surface cyclone (Fig. 3.35c). Severe gradient winds were also reported in the northwest of the surface cyclone in the vicinity of lightning flash reports that occurred within 20 min of 0800 UTC (Fig. 3.35c).
At 1200 UTC 16 April, wind gusts in excess of 40 kt were observed along the Atlantic coast in Massachusetts and Maine, as well as in eastern Pennsylvania and southern New Jersey (Fig. 3.35d). Severe gradient winds were reported in central Vermont (Fig. 3.35d).

At 1800 UTC 16 April, wind gusts in excess of 40 kt were observed along the Atlantic coast in Maine, eastern New Hampshire, Maryland, and northeastern Virginia (Fig. 3.35e). Severe gradient winds were reported in Maine (Fig. 3.35e).

3.3.2.4 Diagnosis of high winds

Severe high winds impacted the northeast quadrant of the 15–16 April surface cyclone throughout the 15–16 April event. Radiosonde data from Chatham, MA (CHH), at 0000 and 1200 UTC 16 April show strong temperature inversions immediately above the surface (Figs. 3.36a,b), which would likely inhibit turbulent transport of high momentum air to the surface. The lapse rate associated with the temperature inversion in the 0000 UTC 16 April CHH sounding was −7.3 K km$^{-1}$ from 966 to 898 hPa (Fig. 3.36a). At 1200 UTC 16 April the lapse rate associated with the temperature inversion in the CHH sounding was −1.7 K (km)$^{-1}$ from 980 to 925 hPa (Fig. 3.36b). Southeasterly wind speeds 16 m above the surface were measured at 50 kt for the 0000 and 1200 UTC CHH soundings (Figs. 3.36a,b).

The southwest quadrant of the surface cyclone was also impacted by strong wind gusts. Radiosonde data from Wallops Island, VA (WAL), and Sterling, VA (IAD), at 0000 UTC 16 April show temperature inversions from the surface to approximately 900 hPa (Fig. 3.37a) and from approximately 925 hPa to approximately 850 hPa, respectively.
For example, the lapse rate from the surface to approximately 900 hPa for WAL at 0000 UTC 16 April was $-4.7 \text{ K km}^{-1}$ (Fig. 3.37a). Temperature inversions would likely inhibit turbulent transport of high momentum air to the surface. Wind speeds at the lowest level for the WAL and IAD were 14 and 18 kt, respectively (Figs. 3.37a,b).

The 1200 UTC 16 April soundings from WAL, IAD, and Aberdeen Proving Ground (APG), MD, are shown in Figs. 3.38a–c. The PBL lapse rates at all three locations were nearly dry adiabatic (Figs. 3.38a–c). For example, the lapse rate from the surface to 795 hPa for WAL at 1200 UTC 16 April was $8.5 \text{ K km}^{-1}$ (Fig. 3.38a). For the 1200 UTC 16 April soundings for WAL, IAD, and APG, winds in the layers where the lapse rates were nearly dry adiabatic were northwesterly and measured near 50 kt (Figs. 3.38a–c). Strong PBL winds in the presence of steep PBL lapse rates likely promoted turbulent transport of high momentum air to the surface. The 0000 UTC 17 April soundings from WAL and IAD indicate that steep PBL lapse rates and strong flow in the PBL persisted from 1200 UTC 16 April to 0000 UTC 17 April (Figs. 3.38a,b and 3.39a,b).

Lightning flashes were reported in the vicinity of observed wind gusts in excess of 40 kt and severe gradient-wind reports on Long Island, NY, at 0300 UTC (Fig. 3.35a), in Delaware at 0600 UTC (Fig. 3.35b), and on the border of New Jersey and Pennsylvania at 0800 UTC 16 April (Fig. 3.35c). At 0300 and 0800 UTC 16 April there was essentially no most unstable CAPE (MUCAPE) present near the border of New Jersey and Pennsylvania or on Long Island, NY (Figs. 3.40a,c). However, a region of very small MUCAPE values between 5 and 10 J kg$^{-1}$ was present in southern Delaware.
at 0600 UTC (Fig. 3.40b), which is where radar echoes exceeded 50 dBZ at 0600 UTC (Fig. 3.35b). The fact that lightning flashes were reported in locations characterized by no MUCAPE suggests that the analysis may not represent the true mesoscale MUCAPE distribution. The occurrence of lightning flash reports in the vicinity of the observed wind gusts and reported severe gradient winds suggests that thunderstorm-related wind gusts occurred during the 15–16 April event.

In association with a dry-air intrusion (Figs. 3.41a,b) and upward-decreasing equivalent potential temperature advection (Figs. 3.41c,d), a region of potential instability developed on the warm side of the baroclinic zone over New Jersey (Fig. 3.33c) at 0600 UTC 16 April (Fig. 3.41d). Frontogenesis occurred along this baroclinic zone at 0000 and 0600 UTC (Figs. 3.41e,f). Ascent occurred on the warm side of the baroclinic zone in the presence of the potentially unstable region at 1200 UTC (Figs. 3.41d,f). As previously noted in section 3.3.1.4, ascent in the presence of layers of potential instability is conducive to thunderstorm and thunderstorm-related downdraft development.

3.3.2.5 Summary

The 15–16 April event was associated with gradient-wind reports that occurred in the northeast, northwest, and southwest quadrants of a surface cyclone. Soundings taken in the northeast quadrant indicated strong temperature inversions. Wind speeds on the order of 50 kt were measured 16 m above the surface. Although a strong temperature inversion would likely inhibit turbulent transport of high momentum air to the surface, the presence of 50 kt wind speeds at 16 m above the surface in the northeast quadrant of the cyclone was likely sufficient to permit downward transport of high momentum air to
the surface. Rapid cyclogenesis led to the development of $-24$ and $12$ hPa $(12 \text{ h})^{-1}$ pressure falls and rises, respectively, a strong isallobaric gradient, and $10$ kt isallobaric winds in the northeast quadrant of the surface cyclone. It is likely the low-level winds were enhanced by the isallobaric wind. Wind gusts in excess of $40$ kt were observed in the southwest quadrant of the cyclone. Wind speeds near $50$ kt in the presence of nearly dry-adiabatic PBL lapse rates provided a favorable environment for turbulent transport of high momentum air to the surface. High winds also occurred in the northwest quadrant of the surface cyclone at 0800 UTC 16 April. Ascent, likely associated with frontogenesis, in the presence of regions potentially unstable air likely led to the development of thunderstorms and thunderstorm-related downdrafts in the vicinity of a dry-air intrusion. The occurrence of lightning flash reports in the vicinity of the observed wind gusts and reported severe gradient winds suggests that thunderstorm-related wind gusts occurred during the 15–16 April event.
Fig. 3.23. (a) The locations of all high-wind reports associated with the 17 Feb 2006 hybrid high-wind event. (b) A meteogram depicting wind gusts at Saratoga County (NY) Airport.
Fig. 3.24. The track of the hybrid southeast composite cyclone and surface cyclone associated with the 17 Feb 2006 hybrid high-wind event. The black dot and shaded box represent the location and central pressure at \( t = 00 \) h, respectively.
Fig. 3.25. GFS analyses at 0600 UTC 17 Feb 2006 (t = 00 h) depicting the location of the initial NE report (star) as well as: (a) mean sea level pressure (hPa, solid), precipitable water (mm, shaded), 1000–500-hPa thickness (dam, dashed), 1000-hPa total wind (kt, barbs); (b) mean sea level pressure (hPa, solid), 12-h centered mean sea level pressure change [hPa (12 h)$^{-1}$, dashed; increasing indicated in red, decreasing indicated in blue], 1000-hPa isallobaric wind (kt, barbs); (c) 850-hPa geopotential height (dam, solid), temperature ($^{\circ}$C, dashed), total wind (kt, barbs); (d) 700-hPa geopotential height (dam, solid), relative humidity (% shaded), vertical motion (μb s$^{-1}$, dashed; upward indicated in red, downward indicated in blue), total wind (kt, barbs); (e) 500-hPa geopotential height (dam, black), absolute vorticity ($10^{-5}$ s$^{-1}$, shaded), total wind (kt, barbs); and (f) 300-hPa geopotential height (dam, solid), wind speed (kt, shaded), divergence of the horizontal wind ($10^{-5}$ s$^{-1}$, dashed).
Fig. 3.26. Radar images and hourly surface observations of (counterclockwise from top right) pressure (hPa), temperature (°C), dewpoint (°C), wind speed and direction (kt), and any station that reported wind gusts in excess of 40 kt (red) within 10 min from 17 Feb 2006 at (a), (b) 1200, (c), (d) 1500, and (e), (f) 1800 UTC. For panels (b), (d), and (f), lightning flash reports, gradient-wind reports, and thunderstorm-wind reports that occurred within 10 min of the radar image are overlaid and denoted by circles, squares, and stars, respectively.
Fig. 3.27. GFS analyses at 17 Feb 2006 depicting 500-hPa geopotential height (dam, black), CAPE (J kg\(^{-1}\), shaded), and 1000–500-hPa shear (kt, barbs) at (a) 1200 and (c) 1800 UTC.
Fig. 3.28. Vertical cross sections from the 1200 UTC 17 Feb 2006 GFS analyses depicting: (a) potential temperature (K, red), relative humidity (%), shaded), potential vorticity ($10^{-6}$ K m$^2$ s$^{-1}$ kg$^{-1}$, black); (b) potential temperature (K, solid), equivalent potential temperature advection ($10^{-4}$ K s$^{-1}$, shaded), potential instability as indicated by the vertical gradient of equivalent potential temperature (K km$^{-1}$, dashed); (c) potential temperature (K, solid), Petterssen frontogenesis [K (100 km)$^{-1}$ (3 h)$^{-1}$, shaded], vertical motion ($\mu$b s$^{-1}$, dashed; upward is indicated in red, downward is indicated in blue); and (d) potential temperature (K, solid), vertical motion ($\mu$b s$^{-1}$, dashed; upward is indicated in red, downward is indicated in blue), total wind (kt, barbs). The orientation of the cross section is indicated in Fig. 3.3a. The inset is a subset of the length of the cross section overlaid on the radar image for 1200 UTC 17 Feb.
Fig. 3.29. As in Fig. 3.28 except at 1800 UTC.
Fig. 3.30. The locations of all high-wind reports associated with the 15–16 Apr 2007 hybrid high-wind event. Also plotted are the lightning flash reports that occurred between 81°W and 65°W and between 38°N and 48°N for 1400 UTC 15 Apr 2007 to 2300 UTC 16 Apr 2007.
Fig. 3.31. The track of the pure gradient northeast composite surface cyclone and surface cyclone associated with the 15–16 Apr 2007 hybrid high-wind event. The black dot and shaded box denote the location and central pressure at t = 00 h, respectively.
Fig. 3.32. As in Fig. 3.25 except for 1800 UTC 15 Apr 2006 (t = 00 h).
Fig. 3.33. As in Fig. 3.25 except for 0600 UTC 16 Apr 2006 ($t = +12$ h) and the location of the initial NE report has been removed. The blue squares denote the locations of [a] [b] [c] [d] [e] [f]
gradient-wind reports that occurred within 10 min of the analysis time. The black line indicates the orientation of the cross sections shown in Figs. 3.41a–e.
Fig. 3.34. As in Fig. 3.26 except for 1200 UTC 16 Apr 2006 (t = +18 h) and the location of the initial NE report has been removed. The blue squares denote the locations of gradient-wind reports that occurred within 10 min of the analysis time.
Fig. 3.35. As in Fig. 3.26 except from 16 Apr 2007 at (a) 0300, (b) 0600, (c) 0800, (d) 1200, and (e) 1800 UTC. Mean sea level pressure analyses from the RUC are plotted as well as lightning flash reports that occurred within 20 minutes of the analysis time.
Fig. 3.36. Skew $T$–log$p$ diagram of temperature (°C), dewpoint (°C), and wind (barbs)
for CHH at (a) 0000 UTC 16 Apr 2007 and (b) 1200 UTC 16 Apr 2007.

Fig. 3.37. As in Fig. 3.36 except at 0000 UTC 16 Apr 2007 for (a) WAL and (b) IAD.
Fig. 3.38. As in Fig. 3.36 except at 1200 UTC 16 Apr 2007 for (a) WAL, (b) IAD, and (c) APG.
Fig. 3.39. As in Fig. 3.36 except at 0000 UTC 17 Apr 2007 for (a) WAL and (b) IAD.

Fig. 3.40. RUC analyses from 16 Apr 2007 depicting 500-hPa geopotential height (dam, black), convective inhibition (J kg\(^{-1}\), dashed), most unstable CAPE (J kg\(^{-1}\), shaded), and 1000–500-hPa shear (kt, barbs) at (a) 0300, (c) 0600, and (c) 0800 UTC.
Fig. 3.41. Vertical cross sections from the 16 Apr 2007 GFS analyses depicting: (a) and (b) potential temperature (K, red), relative humidity (%), shaded), potential vorticity (10^{-6} K m^2 s^{-1} kg^{-1}, black); (c) and (d) potential temperature (K, solid), equivalent potential temperature advection (10^{-4} K s^{-1}, shaded), potential instability as indicated by the vertical gradient of equivalent potential temperature (K km^{-1}, dashed); and (e) and (f) potential temperature (K, solid), Petterssen frontogenesis [K (100 km)^{-1} (3 h)^{-1}, shaded], vertical motion (μb s^{-1}, dashed; upward is indicated in red, downward is indicated in blue). Panels (a), (c), and (e) are for 0000 UTC and panels (b), (d), and (f) are for 0600 UTC. The orientation of the cross section is indicated in Fig. 3.33c.