3.2 Composite analysis

3.2.1 Pure gradient composites

The composite initial NE report in the pure gradient northwest composite (N = 32) occurs where the mean sea level pressure (MSLP) gradient is strongest in a region where a stream of warm moist air is transported poleward (Figs. 3.6a,b). This stream of warm moist air wraps cyclonically around the north side of the composite surface cyclone center toward the location of the composite initial NE report (Fig. 3.6a). The composite initial NE report occurs in a region characterized by precipitable water values between 20 and 24 mm, 1000–850-hPa lapse rates between 3 and 4 K km$^{-1}$, lifted index values between 10 and 13 K, and 1000–500-hPa shear values near 45 kt (Figs. 3.6a–c). Warm advection is occurring at 850 hPa in the vicinity of the composite initial NE report (Fig. 3.6b). The composite surface cyclone is located downstream of a 300-hPa trough axis where there is horizontal divergence of the total wind (Figs. 3.6a,d), which is favorable for cyclogenesis and strengthening of low-level wind speeds. The composite 300-hPa wind speed analysis can be misleading. Although the composite 300-hPa wind speed analysis indicates two jet streaks (Fig. 3.6d), subjective analysis indicates that 14 events were associated with two jet streaks, whereas six and nine events were associated with an entrance and exit region of a jet streak, respectively. Three events were deemed ambiguous. Thus, there is uncertainty regarding the preferred jet structure associated with pure gradient northwest events. Northeast of the composite surface cyclone, MSLP falls are approximately 12 hPa (12 h$^{-1}$) (Fig. 3.6e). The composite initial NE report occurs where the isallobaric, or MSLP tendency, gradient is strongest (Fig. 3.6e).
The composite initial NE report in the pure gradient southwest composite (N = 55) occurs in a region where the MSLP gradient is strongest (Fig. 3.7a). The environment in which the composite initial NE report occurs is characterized by precipitable water values less than 12 mm, 1000–850-hPa lapse rates between 6 and 7 K km\(^{-1}\), lifted index values between 13 and 16 K, and 1000–500-hPa shear values near 35 kt (Figs. 3.7a–c). Cold advection is occurring at 850 hPa in the vicinity of the composite initial NE report (Fig. 3.7b). As in the pure gradient northwest composite, the composite surface cyclone is located downstream of a 300-hPa trough axis where there is horizontal divergence of the total wind (Figs. 3.7a,d), which is favorable for cyclogenesis and strengthening of low-level wind speeds. As was the case with the pure gradient northwest composite, there is uncertainty regarding the preferred 300-hPa jet structure associated with pure gradient southwest events. Although the 300-hPa wind speed analysis indicates a single jet streak with the composite surface cyclone located in the poleward-jet exit region (Figs. 3.7a,d), subjective analysis indicates that 25 events were associated with an exit region of a jet streak, whereas 3 and 24 events were associated with an entrance region of a jet streak and two jet streaks, respectively. Three events were deemed ambiguous. The composite initial NE report occurs within the isallobaric gradient where MSLP is rising (Fig. 3.7e). The minimum in MSLP appears to extend northeastward from the composite cyclone center (Fig. 3.7e), which is a reflection of large latitudinal and longitudinal variation in the location of the individual surface cyclones that make up the composite. The composite initial NE report in the southwest composite cross section typically occurs in a region of strong northwesterly flow, subsidence, and cold advection as indicated by a backing wind profile (Fig. 3.8). A
composite sounding taken at the location of the composite initial NE report at $t = -06 \, h$, $t = 00 \, h$, and $t = +06 \, h$ indicates that at low levels from $t = -06 \, h$ to $t = +06 \, h$ the profile cools as indicated by the temperature profile shifting to colder temperatures, becomes drier as indicated by an increase in the dewpoint depression, and the wind speeds strengthen at all levels (Fig. 3.9). Cooling at 925 hPa is greater than at 1000 hPa, which allows for an approximately dry adiabatic 1000–925-hPa lapse rate to develop at $t = +06 \, h$ (Fig. 3.9). Steep low-level lapse rates promote turbulent transport of high momentum air to the surface.

The composite initial NE report in the pure gradient southeast composite ($N = 45$) occurs in a region where a stream of warm moist air is transported poleward ahead of an imminent cold-frontal passage (Figs. 3.10a,b). The environment in which the composite initial NE report occurs is characterized by precipitable water values between 20 and 24 mm, 1000–850-hPa lapse rates between 3 and 4 K km$^{-1}$, lifted index values between 10 and 13 K, and 1000–500-hPa shear values near 50 kt (Figs. 3.10a–c). Cold and warm advection is occurring at the trough base and ridge crest, respectively, which suggests that the 500-hPa flow pattern is amplifying (Fig. 3.10c). The pure gradient southeast composite surface cyclone is located beneath a region where there is horizontal divergence of the total wind (Figs. 3.10a,d), which is favorable for cyclogenesis and strengthening of low-level wind speeds. As in the previous composites, the composite 300-hPa wind speed analysis can be misleading. Although the 300-hPa wind speed analysis indicates two jet streaks (Fig. 3.10d), subjective analysis indicates that 28 events were associated with two jet streaks, whereas 2 and 13 events were associated with an entrance and exit region of a jet streak, respectively. Two events were deemed
ambiguous. As in the pure gradient southwest composite, the isallobaric couplet for the pure gradient southeast composite differs from the pure gradient northwest composite in that the MSLP rises west of the composite surface cyclone are more rapid in the pure gradient southeast composite (Fig. 3.10e). The composite initial NE report occurs approximately in the location of the strongest isallobaric gradient where the MSLP is falling (Fig. 3.10e). A cross section through the line drawn in Fig. 3.5a reveals the composite initial NE report occurs in a region of ascent ahead of a cold front where the relative humidity at the surface is approximately 85% and the 1000-hPa wind speeds are strongest (Fig. 3.11).

The composite initial NE report in the pure gradient northeast composite (N = 33) occurs where the MSLP gradient is strongest (Fig. 3.12a). The composite initial NE report occurs where a stream of warm moist air is transported poleward in the presence of onshore flow along the Atlantic coast (Fig. 3.12a). Reduced frictional drag is typically observed over the ocean, which allows low-level wind speeds along the Atlantic coast to be stronger compared to over land (Stull 1988, p. 213). The environment in which the composite initial NE report occurs is characterized by precipitable water values between 20 and 24 mm, 1000–850-hPa lapse rates less than 3 K km$^{-1}$, lifted index values greater than 16 K, and 1000–500-hPa shear values near 60 kt (Figs. 3.12a–c). Warm advection is occurring at 850 hPa in the vicinity of the composite initial NE report (Fig. 3.12b). As in the pure gradient northwest, southwest, and southeast composites, the northeast composite surface cyclone is located downstream of an upper-level trough axis where there is horizontal divergence of the total wind (Fig. 3.12d), which is favorable for cyclogenesis and strengthening of low-level wind speeds. There is uncertainty regarding
the preferred 300-hPa jet structure associated with the pure gradient northeast composite. Although the composite 300-hPa wind speed analysis indicates two jet streaks (Fig. 3.12d), subjective analysis indicates that 16 events were associated with two jet streaks, whereas 10 and 6 events were associated with an entrance and exit region of a jet streak, respectively. One event was deemed ambiguous. Unlike the pure gradient northwest, southwest, and southeast composites, the composite initial NE report for the northeast composite occurs at the isallobaric minimum instead of in a region where the isallobaric gradient is strong (Fig. 3.12e).

3.2.2 Hybrid composites

The composite initial NE report in the hybrid northwest composite (N = 8) occurs where the mean sea level pressure (MSLP) gradient is strongest in a region where a stream of warm moist air is transported poleward (Figs. 3.13a,b). This stream of warm moist air wraps cyclonically around the north side of the composite surface cyclone center toward the location of the composite initial NE report (Fig. 3.13a). The composite initial NE report occurs in a region characterized by precipitable water values between 20 and 24 mm, 1000–850-hPa lapse rates between 4 and 5 K km\(^{-1}\), lifted index values between 10 and 13 K, and 1000–500-hPa shear values near 50 kt (Figs. 3.13a–c). Warm advection is occurring at 850 hPa in the vicinity of the composite initial NE report (Fig. 3.13b). The composite surface cyclone is located downstream of a 300-hPa trough axis where there is horizontal divergence of the total wind (Figs. 3.13a,d), which is favorable for cyclogenesis and strengthening of low-level wind speeds. The composite 300-hPa wind speed analysis can be misleading. Although the composite 300-hPa wind speed
analysis indicates two jet streaks (Fig. 3.13d), subjective analysis indicates that four events were associated with two jet streaks, whereas two events each were associated with an entrance and exit region of a jet streak, respectively. No events were deemed ambiguous. Thus, there is uncertainty regarding the preferred jet structure associated with pure gradient northwest events. Northeast of the composite surface cyclone, MSLP falls are approximately 18 hPa (12 h)$^{-1}$ (Fig. 3.13e). The composite initial NE report occurs where the isallobaric, or MSLP tendency, gradient is strongest (Fig. 3.13e). The hybrid northwest events average less than one thunderstorm-wind report per event. Six of the eight hybrid northwest events did not accumulate any thunderstorm-wind reports, and were deemed hybrid events because a lightning flash report occurred within the vicinity of a gradient-wind report.

The composite initial NE report in the hybrid southwest composite (N = 14) occurs in a region where the MSLP gradient is strongest (Fig. 3.14a). The environment in which the composite initial NE report occurs is characterized by precipitable water values between 12 and 16 mm, 1000–850-hPa lapse rates between 6 and 7 K km$^{-1}$, lifted index values between 7 and 10 K, and 1000–500-hPa shear values near 50 kt (Figs. 3.14a–c). Cold advection is occurring at 850 hPa in the vicinity of the composite initial NE report (Fig. 3.14b). The composite surface cyclone is located downstream of a 300-hPa trough axis where there is horizontal divergence of the total wind (Figs. 3.14a,d), which is favorable for cyclogenesis and strengthening of low-level wind speeds. There is uncertainty regarding the preferred 300-hPa jet structure associated with hybrid southwest events. Although the 300-hPa wind speed analysis indicates a single jet streak with the composite surface cyclone located in the poleward-jet exit region (Figs. 3.14a,d),
subjective analysis indicates that five events were associated with an exit region of a jet streak, whereas two and six events were associated with an entrance region of a jet streak and two jet streaks, respectively. One event was deemed ambiguous. The composite initial NE report occurs within the isallobaric gradient where MSLP is rising (Fig. 3.14e). The hybrid southwest composite differs from the pure gradient southwest composite in the following ways: 1) the MSLP does not exhibit the northeastward extension as is evident in the pure gradient southwest composite, which is a reflection of less latitudinal and longitudinal variation in the location of the individual cyclones that constitute the hybrid southwest composite compared to the individual cyclones that constitute the pure gradient southwest composite; and 2) the composite initial NE report is located in a region that is slightly warmer, more moist, and less stable (as indicated by lower lifted index values) compared to the pure gradient southwest composite (Figs. 3.7a–c). As in the pure gradient southwest composite, the hybrid southwest composite is associated with 1000–850-hPa lapse rate values between 6 and 7 K km$^{-1}$ (Fig. 3.14b).

The hybrid southeast composite (N = 71) represents the typical synoptic environment of most high-wind events, based upon the number of members in the composite. The composite initial NE report occurs in a region where warm moist air is drawn poleward from the Gulf of Mexico (Fig. 3.15a). The composite initial NE report occurs in a region characterized by precipitable water values between 24 and 28 mm, 1000–850-hPa lapse rates between 4 and 5 K km$^{-1}$, lifted index values between 4 and 7 K, and 1000–500-hPa shear values near 50 kt (Figs. 3.15a–c). The 850-hPa wind and temperature composite analyses indicate that a cold-frontal passage is imminent in the vicinity of the composite initial NE report (Fig. 3.15b). The 500-hPa flow and 1000–
500-hPa thickness pattern indicates that cold and warm advection is occurring at the 500-hPa trough base and ridge crest, respectively, which suggests the 500-hPa flow pattern is amplifying at the time of the composite initial NE report (Fig. 3.15c). The composite surface cyclone typically occurs downstream of a 300-hPa trough axis where there is horizontal divergence of the total wind (Fig. 3.15d). Although the composite 300-hPa wind speed analysis suggests a single jet streak configuration (Fig. 3.15d), subjective analysis indicates that 27 events were associated with two jet streaks, whereas 15 and 26 events were associated with an entrance and exit region of a jet streak, respectively. Three events were deemed ambiguous. Thus, there is uncertainty regarding the preferred jet structure associated with hybrid southeast events. The composite initial NE report again occurs where the isallobaric gradient is the strongest (Fig. 3.15e). A vertical cross section taken through the line in Fig. 3.15a indicates the composite initial NE report occurs at the leading edge of a cold front where ascent is occurring in the presence of potentially unstable air (Fig. 3.16). A comparison of the hybrid and pure gradient southeast composite cross sections reveals that the pure gradient southeast composite depicts more stable air (equivalent potential temperature increases with height at a greater rate) and does not indicate a region of potential instability at the leading edge of a cold front (Figs. 3.11 and 3.16). Sufficiently lifting the moist, potentially unstable air would allow for thunderstorms and thunderstorm-related downdrafts to develop along the cold front. For the hybrid southeast events, 29 (41%) of the initial NE reports for the hybrid southeast events were thunderstorm-wind reports, suggesting that severe gradient winds that occur ahead of a cold front mix down to the surface prior to the occurrence of thunderstorm-related downdrafts.
The composite initial NE report in the pure gradient northeast composite (N = 30) occurs where the MSLP gradient is strongest (Fig. 3.17a). As in the pure gradient northeast composite, the composite initial NE report occurs where a stream of warm moist air is transported poleward in the presence of onshore flow along the Atlantic coast (Fig. 3.17a). Reduced frictional drag is typically observed over the ocean, which allows low-level wind speeds along the Atlantic coast to be stronger compared to over land (Stull 1988, p. 213). The environment in which the composite initial NE report occurs is characterized by precipitable water values between 24 and 28 mm, 1000–850-hPa lapse rates less than 3 K km$^{-1}$, lifted index values between 7 and 10 K, and 1000–500-hPa shear values near 60 kt (Figs. 3.17a–c). Warm advection is occurring at 850 hPa in the vicinity of the composite initial NE report (Fig. 3.17b). The hybrid northeast composite surface cyclone is located downstream of an upper-level trough axis where there is horizontal divergence of the total wind (Fig. 3.17d), which is favorable for cyclogenesis and strengthening of low-level wind speeds. There is uncertainty regarding the preferred 300-hPa jet structure associated with the hybrid northeast composite. Although the composite 300-hPa wind speed analysis indicates two jet streaks (Fig. 3.17d), subjective analysis indicates that 10 events were associated with two jet streaks, whereas 12 and 8 events were associated with an entrance and exit region of a jet streak, respectively. No events were deemed ambiguous. As in the pure gradient northeast composite, the composite initial NE report for the hybrid northeast composite occurs at the isallobaric minimum (Fig. 3.17e). The hybrid northeast composite initial NE report occurs in region that is warmer, more moist, and less stable (Figs. 3.17a–c; as indicated by lower lifted index values) compared to the pure gradient northeast composite (Figs. 3.12a–c). The
hybrid northeast events average approximately six thunderstorm-wind reports per event. Of the 30 hybrid northeast events, 13 events did not accumulate any thunderstorm-wind reports, but were considered hybrid events because a lightning flash report occurred within the vicinity of a gradient-wind report. Only 3 of the 17 hybrid northeast events that accumulated a thunderstorm-wind report began with a thunderstorm-wind report.

3.2.3 Pure convective composites

The pure convective trough composite (N = 34) is typically associated with a surface cyclone located to the northwest of the composite initial NE report (Fig. 3.18a). Similar to the hybrid southeast composite (Figs. 3.15b), the pure convective trough composite initial NE report occurs in association with a cold-frontal passage (Fig. 3.18b). The composite initial NE report also occurs in a region of near 35 kt 1000–500-hPa shear values coincide with lifted index values between −0.5 and 1 K (Fig. 3.18c). The 500-hPa flow pattern appears to be less amplified (Fig. 3.18c) and the 300-hPa jet streak wind speeds appear to be weaker (Fig. 3.18d) compared to the hybrid southeast composite (Fig. 3.15d). The composite initial NE report occurs in region characterized by ascent in the presence of potentially unstable air (Fig. 3.19). Sufficiently lifting potentially unstable air would allow for thunderstorms and thunderstorm-related downdrafts to form.

The pure convective ridge composite (N = 9) consists of a northwest-to-southeast oriented baroclinic zone located over the NE with the composite initial NE report occurring on the warm side of the baroclinic zone (Fig. 3.20a). Warm advection is evident at 850 hPa (Fig. 3.20b). The composite initial NE report occurs in a region characterized by 1000–850-hPa lapse rates between 3 and 4 K km\(^{-1}\) (Fig. 3.20b). The
composite initial NE report also occurs in a region of near 40 kt 1000–500-hPa shear values coincide with lifted index values between 1 and 4 K (Fig. 3.20c). The composite initial NE report occurs in the equatorward entrance region of a 300-hPa northwesterly jet where there is horizontal divergence of the total wind (Fig. 3.20d). A cross section through the baroclinic zone indicated in Fig. 3.20a reveals that the composite initial NE report occurs in a region of ascent in the presence of potentially unstable air (Fig. 3.21). The presence of dry air at midlevels suggests that entrainment of dry air and evaporative cooling could play a role in the development of thunderstorm-related downdrafts.

3.2.4 Composite surface cyclone tracks

Composite surface cyclone tracks for each pure gradient and hybrid subcategory are presented in Figs. 3.22a and b, respectively. The composite surface cyclone center tends to track from southwest to northeast for all composite subcategories. Based upon the number of events associated with the hybrid southeast composite, the most common surface cyclone track is the hybrid southeast composite. The pure gradient northwest, southwest, and northeast composite surface cyclone centers tend to track along the coast of the NE, whereas the hybrid southeast and northeast composite surface cyclone centers tend to track further inland along the NE (Fig. 3.22). The hybrid southeast composite surface cyclone track is more meridionally oriented compared to the pure gradient southeast composite surface cyclone track, which is consistent with flow throughout the troposphere in the hybrid southeast composite having a southerly component (Figs. 3.15a–d) compared to the pure gradient southeast composite (Figs. 3.10a–d). Because the hybrid southeast composite surface cyclone originates closer to the Gulf of Mexico (at $t = -24$ h the hybrid southeast composite surface cyclone is located in Missouri whereas the
pure gradient southeast composite surface cyclone is located in Iowa), has more of a meridionally oriented track, and ends at a slightly higher latitude at $t = + 24$ h compared to the pure gradient southeast composite surface cyclone, the hybrid southeast composite surface cyclone would draw warmer, more moist, and thus less stable air to higher latitudes compared to the pure gradient southeast composite surface cyclone. The pure gradient and hybrid northeast composite surface cyclone tracks differ in that the hybrid northeast composite surface cyclone tracks north of the composite initial NE report along the interior of the NE, whereas the pure gradient northeast composite surface cyclone tends to track slightly south of the composite initial NE report along the coast (Figs. 3.22a,b). The composite cyclone tracks relative to the composite initial NE reports for the hybrid northwest, southwest, and southeast composites are consistent with the pure gradient northwest, southwest, and southeast composite cyclone tracks (Figs. 3.22a,b).
Fig 3.6. Pure gradient northwest composite (N = 32) depicting the location of the composite initial NE report (star) and: (a) MSLP (hPa, solid), 1000–500-hPa thickness (dam, dashed), precipitable water (mm, shaded), 1000-hPa total wind (kt, barbs); (b) 850-hPa geopotential height (dam, solid), temperature (°C, dashed), 1000–850 lapse rate (K km$^{-1}$, shaded), 850-hPa total wind (kt, barbs); (c) 500-hPa geopotential height (dam, solid), 1000–500-hPa thickness (dam, dashed), lifted index (K, shaded), 1000–500-hPa shear vector (kt, barbs); (d) 300-hPa geopotential height (dam, solid), horizontal divergence of the total wind (10$^{-5}$ s$^{-1}$, dashed), wind speed (kt, shaded), 300-hPa total wind (kt, barbs); and (e) MSLP (hPa, solid) and 12-h centered MSLP change [hPa (12 h)$^{-1}$, dashed].
Fig. 3.7. As in Fig 3.1 except for the pure gradient southwest composite (N = 55). The black line in panel (a) indicates the orientation of the cross section shown in Fig. 3.8.
Fig. 3.8. Pure gradient southwest composite \((N = 55)\) cross section depicting equivalent potential temperature \((\text{K, solid})\), vertical motion \((10^{-3} \text{ Pa s}^{-1}, \text{dashed; upward indicated in red, downward indicated in blue})\), relative humidity \((\%, \text{shaded})\), horizontal component of the total wind \((\text{kt, barbs})\), and the location of the initial NE report \((\text{star})\).

Fig. 3.9. Pure gradient southwest composite \((N = 55)\) soundings taken at the location of the initial NE report at \(t = -06\) h \((\text{red})\), \(t = 00\) h \((\text{purple})\), and \(t = +06\) h \((\text{blue})\).
Fig. 3.10. As in Fig 3.1 except for the pure gradient southeast composite (N = 45). The black line in panel (a) indicates the orientation of the cross section shown in Fig. 3.11.
Fig. 3.11. As in Fig. 3.3 except for the pure gradient southeast composite (N = 45).
Fig. 3.12. As in Fig 3.1 except for the pure gradient northeast composite (N = 33).
Fig. 3.13. As in Fig 3.1 except for the hybrid northwest composite (N = 8).
Fig. 3.14. As in Fig 3.1 except for the hybrid southwest composite (N = 14).
Fig. 3.15. As in Fig 3.1 except for the hybrid southeast composite (N = 71). The black line in panel (a) indicates the orientation of the cross section shown in Fig. 3.16.
Fig. 3.16. As in Fig. 3.3 except for the hybrid southeast composite (N = 71).
Fig. 3.17. As in Fig 3.1 except for the hybrid northeast composite (N = 30).
Fig. 3.18. As in Fig. 3.1 except for the pure convective trough composite (N = 34). The black line in panel (a) indicates the orientation of the cross section shown in Fig. 3.19.

Fig. 3.19. As in Fig. 3.3 except for the pure convective trough composite (N = 34).
Fig. 3.20. As in Fig 3.1 except for the pure convective ridge composite (N = 9). The black line in panel (a) indicates the orientation of the cross section shown in Fig. 3.21.

Fig. 3.21. As in Fig. 3.3 except for the pure convective ridge composite (N = 9).
Fig. 3.22. Composite surface cyclone tracks for each subcategory based upon the location of the composite cyclone center at 6-hourly time intervals for the (a) pure gradient and (b) hybrid event types. The shaded box and black dot represent the central pressure and location of the composite surface cyclone at $t = 00$ h, respectively. The star represents the location of the composite initial NE report. The pure gradient southwest, hybrid southwest, and hybrid northwest composite surface cyclone tracks do not extend to $t = -24$ h, because a coherent center of low MSLP was not evident in the composite at those times.