17A.3 SYNOPTIC-SCALE CONVECTIVE ENVIRONMENT CLIMATOLOGY BY ENSO PHASE IN THE NORTH CENTRAL UNITED STATES

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1. INTRODUCTION

The El Niño-Southern Oscillation (ENSO) is known to affect synoptic patterns across the continental United States, particularly by its impact on the upper tropospheric jet stream position. Global circulation patterns influence synoptic weather patterns by impacting the location of mid-tropospheric ridge and trough locations and thus areas favorable for temperature and precipitation anomalies, which in turn influence regional severe weather activity. Though it is one of several factors associated with the potential for severe weather, the synoptic environment plays a key role in severe weather potential by providing favorable ingredients for the development of severe convection (e.g. Miller 1967). While ENSO is one of many factors that influence global circulations, and by distillation may have a less distinguishable influence on the synoptic pattern, coherent signals can be uncovered in the synoptic environment, based on ENSO phase, that would influence the potential for severe convection in the north central United States. Seasonal predictions of severe weather potential are not much aid for daily operations, but they can be used by emergency managers, the media, and forecasters to increase preparedness for seasons that have the potential for above normal convective activity.

Previous studies have investigated the relationship between ENSO and tornado climatology in the United States and Canada, with varying definitions of ENSO and methodologies (Bove and O'Brien, 1998; Browning 1998; Etkin et al., 2001; Wikle and Anderson, 2003). Agee and Zurn-Birkhimer (1998) determined that an axis of increased tornado activity during La Niña years extended from Iowa through Illinois and Indiana into Kentucky and Tennessee, while an axis of increased tornado activity during El Niño years extended from Colorado and New Mexico through the Texas panhandle into Oklahoma and Missouri. They concluded that their findings were a result of geographical shifts in tornado activity, rather than an overall increase or decrease in activity nationwide based on ENSO phase. Bove (1998) found a similar axis of increased activity in La Niña years. Additionally, Cook and Schaefer (2008) found significant relationships between ENSO phase and winter (January-March) tornado activity in the southern Plains, the Southeast, and the Ohio Valley areas.

Mayes et al (2007; hereafter M07) found statistically significant correlations across parts of the Plains and Mississippi River valley between ENSO phase and tornado activity. An elevated risk of an increased number of tornado days and significant tornadoes was noted in parts of the central Plains and mid-Mississippi River valley during a La Niña, while these areas experienced diminished potential for above average tornado activity (and an increased potential for below average activity) during an El Niño. The results of M07 prompted this study, investigating whether these spatially consistent statistical results had a foundation in the larger scale synoptic pattern influencing convective, and hence tornadic, activity.

The use of reanalysis data is an accepted means to investigate synoptic-scale convective parameters, even though the coarse horizontal and vertical resolution is likely to miss features important to convective development for any given day. Brooks et al. (2007) investigated convective parameters via reanalysis data with the purpose of creating a climatology of those relevant parameters. Schultz et al. (2007) also utilized reanalysis data in an examination of the influence of the

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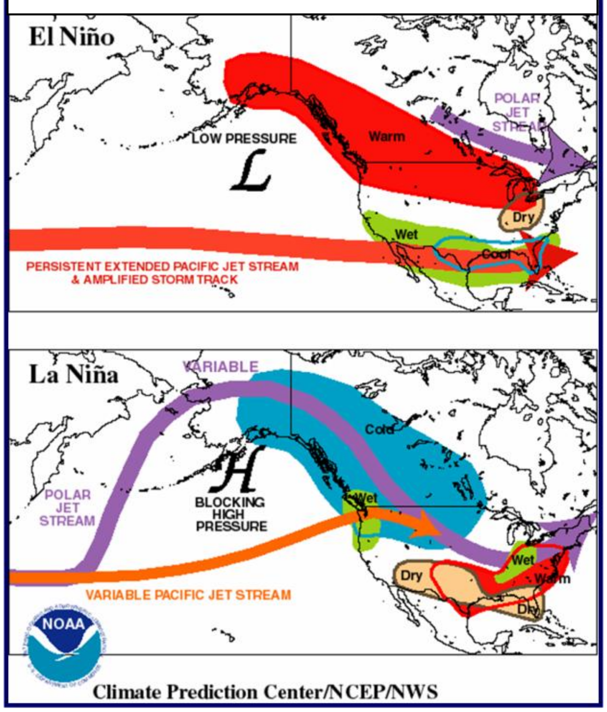
synoptic environment on dryline intensity. While not able to resolve mesoscale and storm-scale features, global reanalysis data can provide insight into the synoptic environment, which certainly influences the potential for convection, including severe weather.

The National Weather Service (NWS) Climate Prediction Center (CPC) has defined typical upper-level jet stream and sensible weather anomalies during January-February-March (Fig. 1). During an El Niño, the subtropical upper-level jet is suppressed southward over the southwestern United States and toward the Gulf of Mexico, inducing anomalously wet conditions across its track. The nearly zonal flow across the northern and central U.S. is typically left drier than average, with warm conditions as the polar jet remains north of the continental United States (e.g., Ropelewski and Halpert, 1987). During a La Niña, the upper-level jet pattern is more amplified and often comes ashore near the Pacific Northwest, inducing wet anomalies there. A blocking high pressure in the Gulf of Alaska often aids a more meridional component to the upper-level flow across the central U.S. and allowing for colder weather to seep into the northern tier. The southern U.S. typically remains drier and warmer than average, with the storm track remaining further north. While individual El Niño and La Niña episodes do deviate to some extent from the typical patterns in Fig. 1, the tendencies are present throughout the varying episodes.

While this study investigates springtime conditions, it is useful to note CPC's ENSO impacts as the antecedent conditions to that season. Similar upper-level flow patterns can be expected in the spring, particularly early in the season as the transition to a summer pattern occurs. It is worth noting that it is beyond the scope of this study to investigate mesoscale and smaller scale features, such as frontal boundaries and locally enhanced low-level shear, that do have an impact on tornadogenesis. Rather, this study focuses on features of the synoptic scale patterns that can be resolved on the coarse grid spacing found in reanalysis data, such as trough patterns and mid and upper level flow, that create an environment favorable for convective activity.

Figure 1. Typical January-March weather anomalies and atmospheric circulation during moderate to strong El Nino and La Nina (from CPC)



2. DATA AND METHODOLOGY

Data used in this paper were selected to be consistent with M07, including the use of an operational definition for ENSO as well as a source of reanalysis data available for the entire study period of 1950-2005.

2.1 ENSO Definition

The National Oceanic and Atmospheric Administration (NOAA) developed an operational definition for ENSO utilizing the Oceanic Niño Index (ONI). ONI is defined as the three-month running average sea surface temperature anomaly in the Niño 3.4 region. An El Niño occurs when ONI is at least 0.5 °C for at least five consecutive 3-monthly periods, or "seasons"; conversely, La Niña conditions occur when ONI reaches –0.5 °C or less for five consecutive seasons.

The ONI has been calculated by 3-month period and is available online via NOAA's Climate Prediction Center (CPC) back to 1950 (Smith and Reynolds, 2003). The NOAA definition of ENSO based on ONI is followed in this study.

2.2 Data Source and Methodology

With the intent of investigating synoptic patterns during the peak of the convective season in the north central United States, the focus was narrowed to the four-month period of March-April-May-June (MAMJ). Each year from 1950 to 2005 was classified based on the ENSO phase present during each three-month period, or "season", affecting MAMJ, ranging from January-February-March through June-July-August. MAMJ periods that began in a given ENSO phase during those seasons affecting MAMJ but ended as neutral were placed in a category for each, "La Niña Going Out" and "El Niño Going Out." MAMJ periods that began as neutral during those seasons affecting MAMJ but transitioned to a given ENSO phase were categorized alongside those MAMJ periods that remained within a given ENSO phase for their entire length, creating categories for "La Niña In or Going In" and "El Niño In or Going In." Finally, seasons remaining in the neutral phase throughout the duration were categorized as such. Four MAMJ periods saw a transition directly from one ENSO phase to the opposite and were left out of the phase-based composites. The years included in

Table 1. Years included in each ENSO phase to create composite images. Years not included were those that switched from one ENSO phase to the opposite during the 3-month seasons overlapping the March-June study period.

Phase	Years
La Niña	
In or Going In	1950, 1954, 1955, 1956, 1964, 1970, 1971, 1974, 1975, 1999
Going Out	1951, 1962, 1968, 1976, 1985, 1989, 1996, 2000, 2001
Neutral	1952, 1953, 1959, 1960, 1961, 1967, 1978, 1979, 1980, 1981, 1984, 1986, 1990
El Niño	
In or Going In	1957, 1963, 1972, 1982, 1987, 1991, 1993, 1994, 1997, 2002, 2004
Going Out	1958, 1966, 1969, 1977, 1983, 1992, 1995, 2003, 2005
Not Included	1965, 1973, 1988, 1998

each category are depicted in Table 1.

Composite images of synoptic parameters were created using National Center for Atmospheric Research (NCAR)/National Centers for Environmental Prediction (NCEP) reanalysis data (Kalnay et al, 1996). The data were obtained via the NOAA Earth Systems Research Laboratory website (http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl). Data were then converted for visualization in the General Meteorological Package software (GEMPAK; DesJardins et al. 1991). Synoptic parameters were investigated based on the five categories delineated in Table 1. Major parameters such as temperature, wind, and geopotential height were available directly, while others such as bulk shear and dewpoint temperature could be derived from the basic parameters available.

3. RESULTS AND DISCUSSION

The synoptic parameters indeed exhibited tendencies based on the five phases investigated. The features examined did resemble the expected synoptic patterns illustrated schematically in Fig. 1, which helps lend credibility to their representativeness of each ENSO phase. Notably, the “in or going in” phases for both El Niño and La Niña did not necessarily resemble the “going out” phase closely. The La Niña In or Going In phase was closest to a classic La Niña schematic, while the El Niño Going Out phase most closely resembled the El Niño schematic.

Standard synoptic fields were examined for each of the five phases, including fields such as 300 hPa winds, 500 hPa geopotential height, 700 hPa temperatures, 850 hPa dewpoint temperatures and winds, and mean sea level pressure. The anomaly fields for each parameter in each phase were examined in relation to the mean fields through the 1950-2005 study period. Features that are accepted as creating a favorable, or hostile, synoptic environment for the development and maintenance of convection were then possible to distinguish in each phase.

3.1. La Niña In or Going In

Perhaps more than any other phase, features during an established or developing La Niña showed distinct trends that may help explain some of the statistical trends noted in M07. In this case, the features support the establishment of a favorable convective environment across much of the central and southern Plains into the mid to lower Mississippi River Valley. At 300 hPa (Fig. 2a), the subtropical upper-level jet is enhanced across the southern Plains, with increased southwesterly flow into the Plains and Midwest. An anomalous upper-level trough is present in the Rockies (Fig. 2b), with the anomalous high over the Gulf of Alaska noted at 500 hPa as well. Temperatures at 700 hPa are anomalously high in the South and cool across the north central and northwestern CONUS (Fig. 2c), indicating an enhancement of the baroclinicity across the central U.S., with anomalously strong southwesterly flow across the central CONUS. The low-level jet at 850 hPa (Fig. 2d) is notably enhanced across the Plains, with a distinct dry pocket extending from the Rockies onto the High Plains. The dry anomaly may indicate an eastward displacement of the mean dryline position, a feature known to aid convective development, and may also indicate an anomalously strong mean dryline. Mean sea level pressure anomalies reflect 500 hPa anomalies (Fig. 2e), with an anomalous surface low in the lee of the Rockies and high pressure off the Northwest Pacific coast.

Overall, anomalous features present during a La Niña are often associated with a favorable synoptic environment for convection, including the potential for tornadic activity. The pattern of a trough in the Rockies, strong southwesterly upper-level flow, an enhanced low-level jet, and the presence of baroclinicity are, as a group, a classic severe weather environment. It is no surprise, then, that large portions of the study area of the north central U.S., particularly the central Plains and the Mississippi River Valley, exhibit an enhanced potential for tornado activity in the highest tercile of the period.

3.2. La Niña Going Out

Features during a weakening La Niña episode do exhibit some of the characteristics of an ongoing or developing La Niña event, but also exhibit a trend toward the neutral conditions (not shown). At 300 hPa (Fig. 3a), the subtropical jet is clearly displaced southward and out of the CONUS, with easterly anomalies across the southern U.S. Northwesterly flow is present across the north central U.S., consistent with an unsettled weather pattern. An anomalously strong upper-level high is present in the western U.S. (Fig. 3b), again supporting northwesterly flow. Temperatures at 700 hPa are anomalously warm across much of the western two-thirds of the U.S. (Fig. 3c), with a cool anomaly further north in Canada creating an area of enhanced baroclinicity across the northern tier of the CONUS. Anomalously strong southerly flow is still evident into the Plains at 850 hPa (Fig. 3d), though not as strong as during an ongoing or developing La Niña. A pool of anomalous moisture is present in the southern and central High Plains. The anomalous low pressure is displaced westward into the Rockies, with a weakening of the lower pressures apparent as a high pressure anomaly in the central Plains toward the Mississippi River valley (Fig. 3e).

Features during a dissipating La Nina do still support convective activity, particularly in the High Plains, where the moisture anomaly and low pressure anomaly best coincide. With northwesterly flow and enhanced baroclinicity in the northern Plains, that region would also be favorable for enhanced convective activity. Again, the convective environment supports the findings of M07.

3.3. El Niño In or Going In

Interestingly, much like a weakening La Niña, the pattern for an established or developing El Niño is something of a blend between the classic El Niño synoptic pattern (Fig. 1) and neutral conditions. Anomalies during this phase are, in general, weaker than the other phases, though still notable enough to deviate from the mean pattern. Winds at 300 hPa are weakened across the central U.S. (Fig. 4a), as during a dissipating La Nina. With an anomalous upper-level low off the coast of the Pacific Northwest (Fig. 4b), however, flow is also weakened in the northern CONUS. Weak anomalous upper-level ridging is induced across most of the CONUS. Little in the way of a temperature change at 700 hPa is present (Fig. 4c), and winds are anomalously weakened as depicted by northeasterly wind anomalies in the mid and lower Mississippi River valley. A weak 850 hPa moisture anomaly is again present in the southern and central High Plains (Fig. 4d), though 850 hPa winds are also suppressed by northeasterly anomalies in the southern Plains toward the mid Mississippi River Valley. In a surface reflection of the upper-level anomalies, mean sea level pressure across the CONUS exhibits high pressure anomalies (Fig. 5e), centered on the northern Rockies and the Gulf states.

Statistical relationship between an ongoing or developing El Niño and tornado activity are weaker than those during a La Niña, and tend to indicate suppression across the southern and central Plains toward the mid Mississippi River Valley. With anomalous upper-level and surface ridging, as well as suppressed mid-level winds, it is not surprising that convection may tend to be suppressed in that environment. Weakened 850-700 hPa winds likely correspond to diminished 0-3 km shear, corresponding to a decreased threat of tornado-producing convection.

3.4. El Niño Going Out

Features during an outgoing El Niño, or in the convective season following a wintertime El Niño, are close to a classic El Niño pattern (Fig. 1). Wind anomalies at 300 hPa indicate that the subtropical jet is displaced southward toward the Gulf of Mexico (Fig. 5a), with diminished flow across much of the CONUS. Anomalous upper-level lows are noted in both the Gulf of Alaska and the southeastern U.S. (Fig. 5b), with a positive height anomaly reaching into the north central and northwestern CONUS, inducing a blocking flow pattern in the north central U.S. Baroclinicity at 700 hPa is decreased, as noted by cool anomalies to the south and warm anomalies to the north, with stronger northeasterly wind anomalies indicating winds across the Plains and Mississippi River Valley are further suppressed (Fig. 5c). Suppressed winds are also noted at 850 hPa (Fig. 5d), with dry anomalies reaching the Midwest and moist anomalies lingering in the Rockies. Mean sea level pressure is again a reflection of the upper-level flow, with anomalous ridging across much of the Plains between low pressure anomalies in the Gulf of Alaska and the southeastern U.S (Fig. 5e).

M07 indicated an increased potential for suppressed tornadic activity following a winter El Niño, a result that is supported by examining the synoptic environment during that phase. Weakened mid-level winds, as well as upper-level and surface anomalous ridging, create a mean environment during this phase that is hostile toward convective development.

4. CONCLUSIONS AND FUTURE WORK

The results of this study indicate that the statistically significant changes to the climatology of tornadic activity noted in M07 can be linked to changes in the synoptic-scale pattern. During a La Niña, and particularly when a La Niña is ongoing throughout or begins during the peak convective season of MAMJ, an anomalous trough in the Rockies, as well as increased baroclinicity across the Plains, support the potential for enhanced tornadic activity. Similarly, during an El Niño, and particularly when an El Niño through the winter months is weakening to a neutral phase, an anomalous upper-level high exists over the central U.S., along with suppressed low-level flow off the Gulf of Mexico, a pattern which is typically not conducive to severe weather in southern portions of the study area. The finding again supports the statistical results from M07 that tornadic activity tends to be suppressed in those regions.

It is important to note that the ENSO cycle is one of many factors that influence weather across the north central U.S. Other less predictable climate signals, such as the North Atlantic Oscillation, and shorter term climate anomalies, such as the Madden-Julian Oscillation, likely also have an influence on large-scale weather patterns. In addition, because tornadoes are ultimately caused by mesoscale or smaller scale environments, the potential for tornado activity on any given day cannot be determined by the ENSO phase occurring. Active tornado seasons do occur in phases that are, on average, not considered as favorable for an active season. Despite these limitations, ENSO does provide at least one measure of predictability of the potential for activity during a season, and this knowledge can be utilized by forecasters and planners alike.

Future work on this study will include examining more parameters that are closely connected with convection, such as instability and shear parameters, as well as investigating point soundings constructed from reanalysis data for any relevant features. It would also be beneficial to look at convective seasons from 2006-2008 in comparison to the findings of both this study and M07 to determine how well the results from individual years compare to the multi-year composites and statistical analyses.

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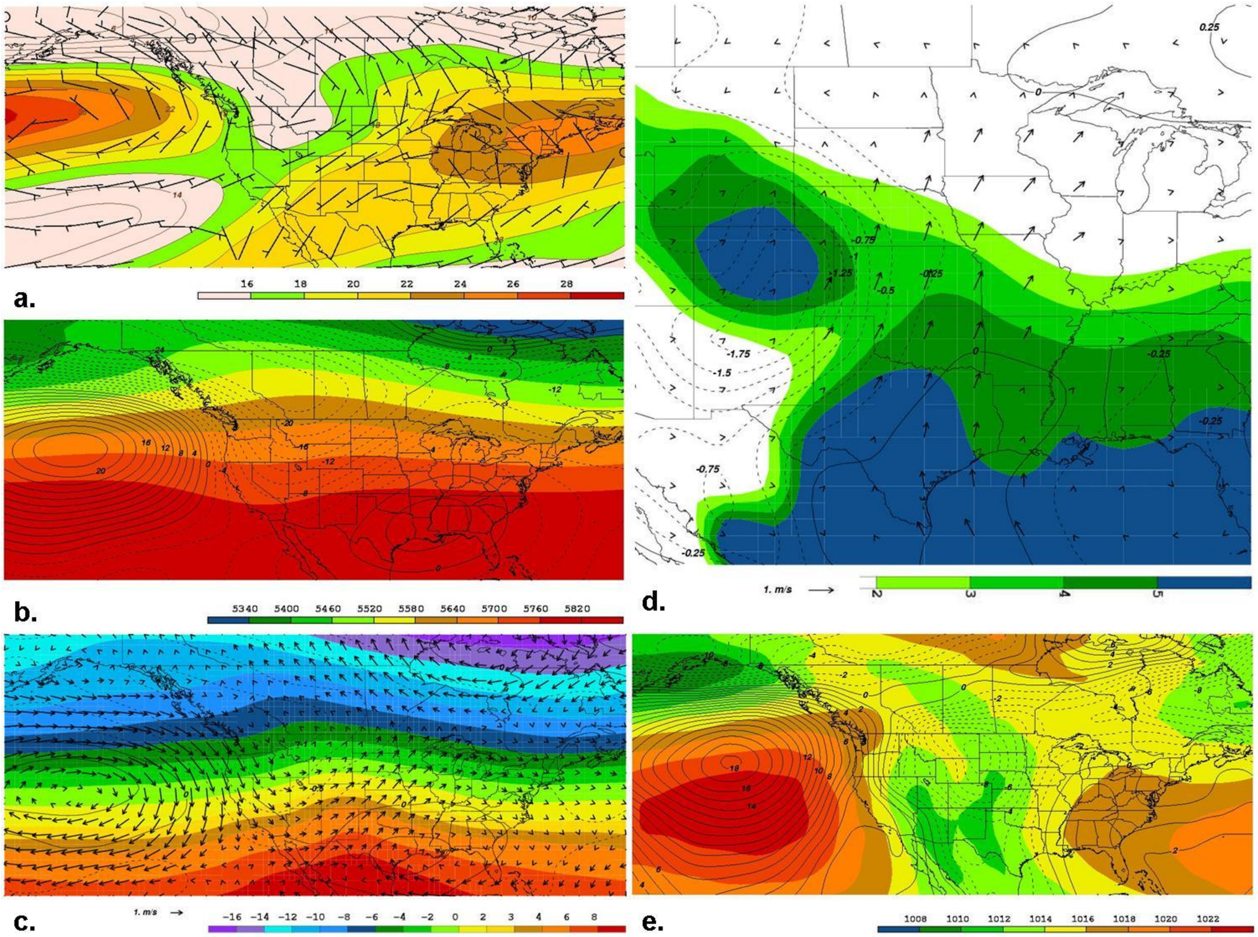

Figure 2. March-June mean and anomalous synoptic fields during an ongoing or developing La Niña ("La Niña In or Going In"). a. 300 hPa mean 1950-2005 winds (shaded) and phase anomalies (barbs). b. 500 hPa mean 1950-2005 geopotential height (shaded) and phase anomalies (contours). c. 700 hPa mean 1950-2005 temperature (shaded), phase temperature anomalies (contours), and phase wind anomalies (vectors). d. 850 hPa mean 1950-2005 dewpoint temperature (shaded), phase dewpoint anomalies (contours), and phase wind anomalies (vectors). e. Mean 1950-2005 mean sea level pressure (shaded) and phase anomalies (contours).

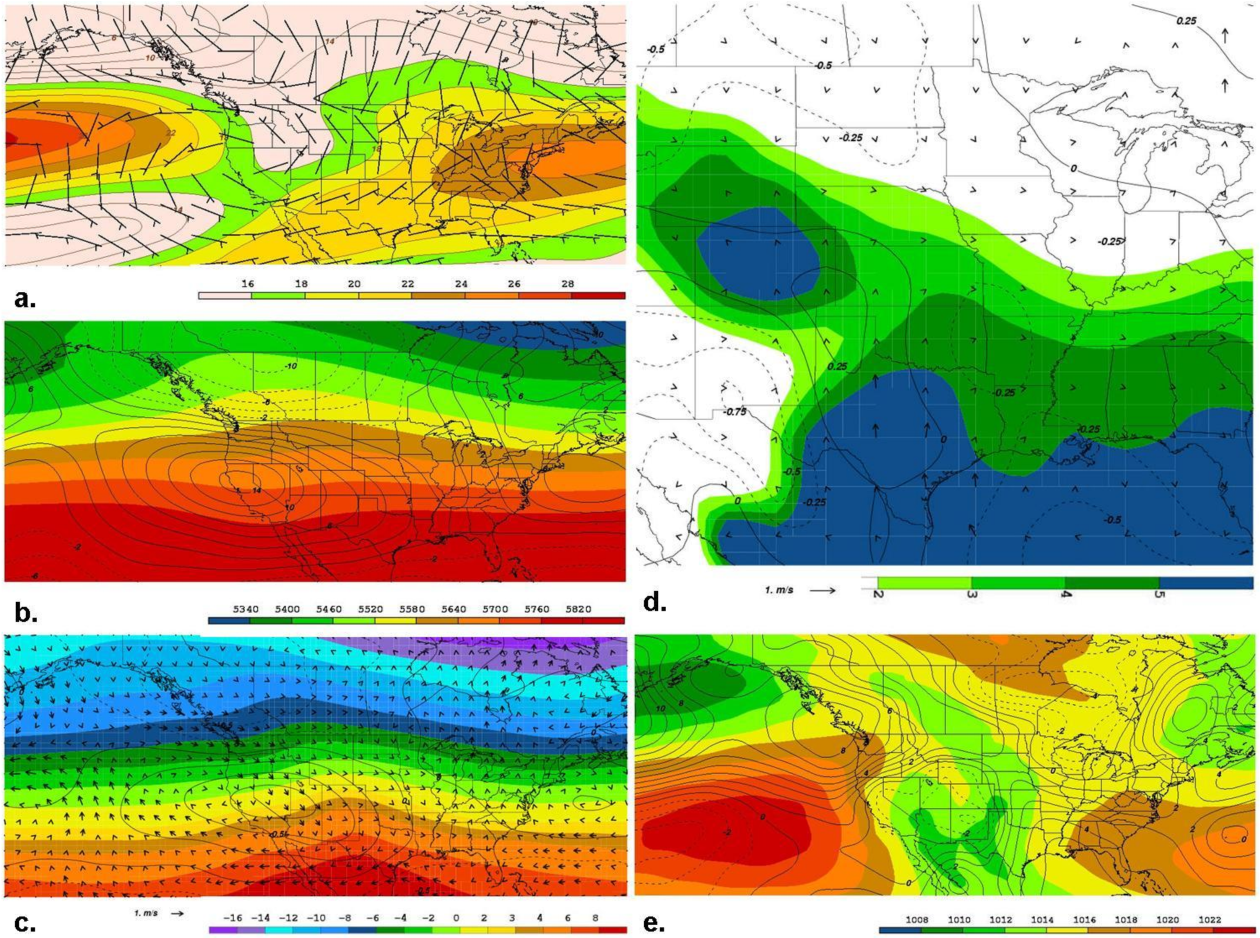

Figure 3. As in Figure 2, but for a weakening La Niña ("La Niña Going Out").

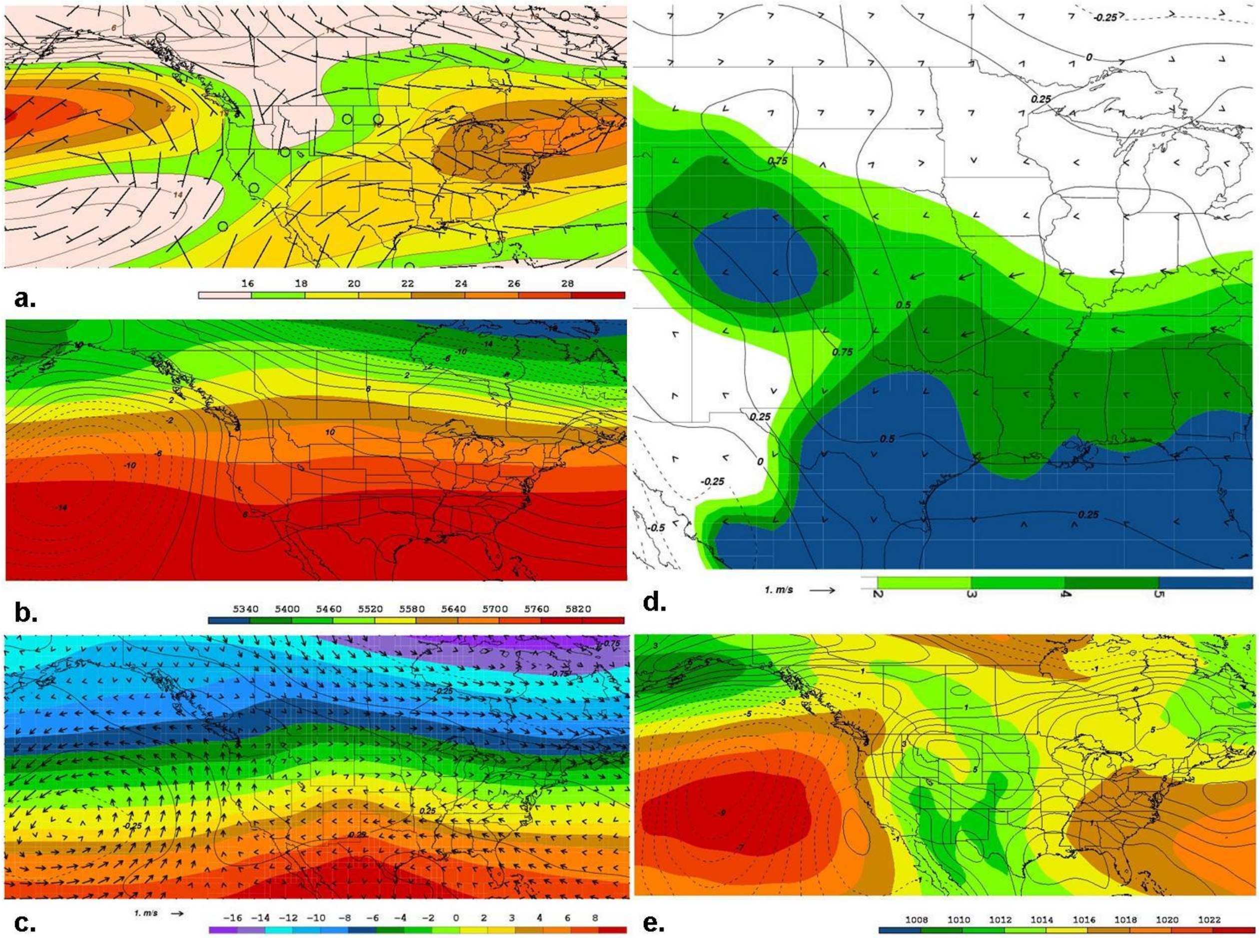

Figure 4. As in Figure 2, but for an ongoing or developing El Niño (“El Niño In or Going In”).

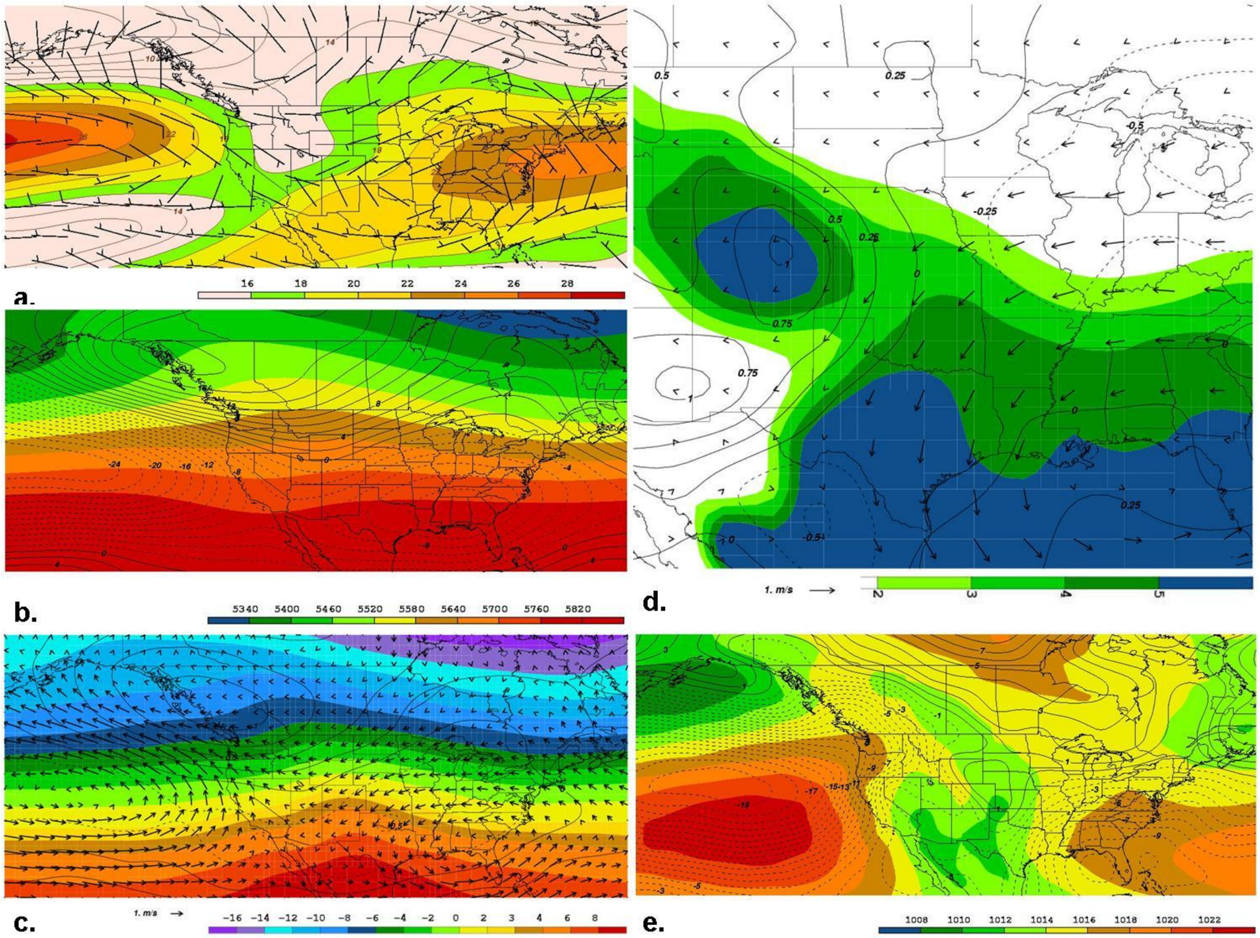

Figure 5. As in Figure 2, but for a weakening El Niño ("El Niño Going Out").