1.1 TORNADO AND SEVERE WEATHER CLIMATOLOGY AND PREDICTABILITY BY ENSO PHASE IN THE NORTH CENTRAL U.S.: A COMPOSITING STUDY

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1. INTRODUCTION

Climatological factors, including the phase of the El Niño-Southern Oscillation (ENSO), are known predictors for parameters such as seasonal temperature and precipitation and tropical cyclone activity. ENSO phase also has a relationship to severe weather activity and may have utility in predicting anomalies in severe weather climatology, including the number of significant tornadoes and the number of tornado days. While not useful in daily severe weather operations and forecasting, determining the relationship between ENSO phase and severe weather climatology anomalies can aid preparedness for potentially active seasons among operational meteorologists, emergency managers, the media, and others with a role in preparing spotters and citizens for severe weather seasons.

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 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.

The north central United States is the focus of this study, encompassing nine states (North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Wisconsin, Iowa, Missouri, and Illinois) in the central and northern Plains and middle and upper Mississippi River valley that are climatologically in the heart of active spring and summer convective seasons. Data are grouped by state as well as by National Weather Service (NWS) Weather Forecast Office (WFO) County Warning Area (CWA) to capture smaller-scale climatological features.

This severe weather compositing study will serve many purposes. Primarily, the study is an investigation of the impact of a large-scale climatological factor that exhibits predictability, ENSO, on smaller-scale weather phenomena, severe convection. Embedded within this study, however, is a case study of the methodology of compositing that will be used operationally by the NWS as the 3-Month Outlook of Local El Niño/La Niña Impacts (3MOLEI) for many weather parameters. For this purpose, examining data at the CWA level will demonstrate the utility of the method for NWS WFO climate operations.

2. DATA AND METHODOLOGY

Conducting a statistical compositing study of severe weather climatology based on ENSO requires a consistent and approved definition of ENSO as well as a quality data set and a rigorous compositing methodology.

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 months; conversely, La Niña conditions occur when ONI reaches –0.5°C or less for five consecutive months.

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The ONI has been calculated by 3-month period, also referred to as “season”, 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

Tornado and severe weather data for this study were collected from NOAA’s National Climatic Data Center (NCDC) Storm Data publication, in both its online database and document formats. Other quality data sets do exist (Grazulis 1993), but their interpretation with relation to the NCDC records can be subjective and can introduce a source of inconsistency. In addition, Grazulis (1993) provides data for significant tornadoes only and not the full tornado record.

The NOAA Storm Data publication does have known limitations, including the upward trend in reports due to increasing population coverage, more aggressive verification practices, and an increase in the number of storm chasers (Verbout et al., 2006). Data missing from the online Storm Data database in June and July 1993 were added manually based on the Storm Data documents. NCDC Storm Data were filtered by the authors to remove reports that did not meet severe criteria (hail 0.75 inches or greater; wind 50 knots or greater) as well as wind reports that were non-convective. Tornadoes in the NCDC database are listed by county; thus, to prevent multiple counts of the same tornado, county border-crossing tornadoes were grouped together as one tornado. Finally, several instances of duplicate reports, particularly during the early 1990s, were removed. The resulting database of well over 150,000 storm reports provides a clean foundation for the study, albeit with the inherent limitations described above.

While the number of tornado reports does show an upward trend with time, particularly in the number of F0 and F1 tornadoes, the number of tornado days and the number of significant (F2 or greater) tornadoes does not show nearly as much of a trend. Therefore, the number of significant tornadoes was used for the entire period of record of ENSO phase (1950-2005), and the number of tornado days was used from 1960-2005. The hail database exhibits a strong upward trend in the number of reports well into the 1990s, even when looking at the number of significant (2 inch or greater) hail days (Doswell et al., 2005); thus, the conditional climatologies using hail records to ENSO phase likely are contaminated by that trend. The wind database was even more inconsistent due to changes in reporting style through the years as winds were estimated, listed at 0 knots, or listed with wind speeds not available when direct measurements were not made. As a result, convective winds have not been addressed in this study.

2.3 Compositing Methodology

The methodology used in this study was developed in partnership among NWS headquarters, CPC, and NWS staff in regional and field offices. Much of the detail about the compositing methodology is available online as training material and templates (http://www.nws.noaa.gov/om/csd/pds/pcu4/IC4.3/index.htm).

The compositing process is scheduled to become an operational forecast product, the 3MOLEI, at the NWS WFOs, with the flexibility for offices to composite any weather or climate parameter that has a statistically meaningful relationship to the ENSO phase as determined by the methodology. The compositing technique incorporates a standardized method for developing climatologies of the given parameter for each ENSO phase (La Niña, neutral, and El Niño) in comparison to the climatology of the period of record, as well as incorporating a test for statistical significance of the results to determine if deviations from the average climatology are significant relative to the null hypothesis that there is no relationship between ENSO phase and each parameter.

The compositing analysis employs a sampling technique based on the conditional probability of a given event occurring based on the ENSO phase. The result is a conditional climatology of a given variable based on the ENSO phase. The conditional climatologies can be combined with forecast probability of an ENSO phase to predict the probability of a given climatological variable occurring in the above, near, or below normal category given the ENSO phase that is forecast to occur; however, the forecast portion of the compositing methodology is not addressed in this study.

In order to test for statistical significance, the compositing analysis methodology determines whether the results are significant to a 90% confidence, or for $p \leq 0.10$. The methodology utilizes a hypergeometric distribution function, $P(x)$, which is used as a proxy to describe the probability distribution among all possible outcomes of a category within a given ENSO phase. The significance test compares the actual number of events that occur near the tails of the tercile distributions (in other words, in the above or below normal terciles) for each phase of ENSO with the probability of (1) at least x number of events occurring and (2) greater than x number of events occurring, where x events is determined based on the 90% confidence ($p \leq 0.10$) criteria. The results indicate which shifts in distribution are statistically significant to 90% confidence relative to the null hypothesis that there is no relationship between ENSO and the severe weather parameter.

This study focuses on developing the conditional climatology of several severe weather climatological variables, including number of tornado days per year and number of significant (F2+) tornadoes per year.

The conditional climatology, rather than the forecast, is emphasized here. The study considers weak, moderate, and strong episodes of El Niño and La Niña to be part of the climatology in those phases, therefore not differentiating ENSO phase by its strength.

3. RESULTS

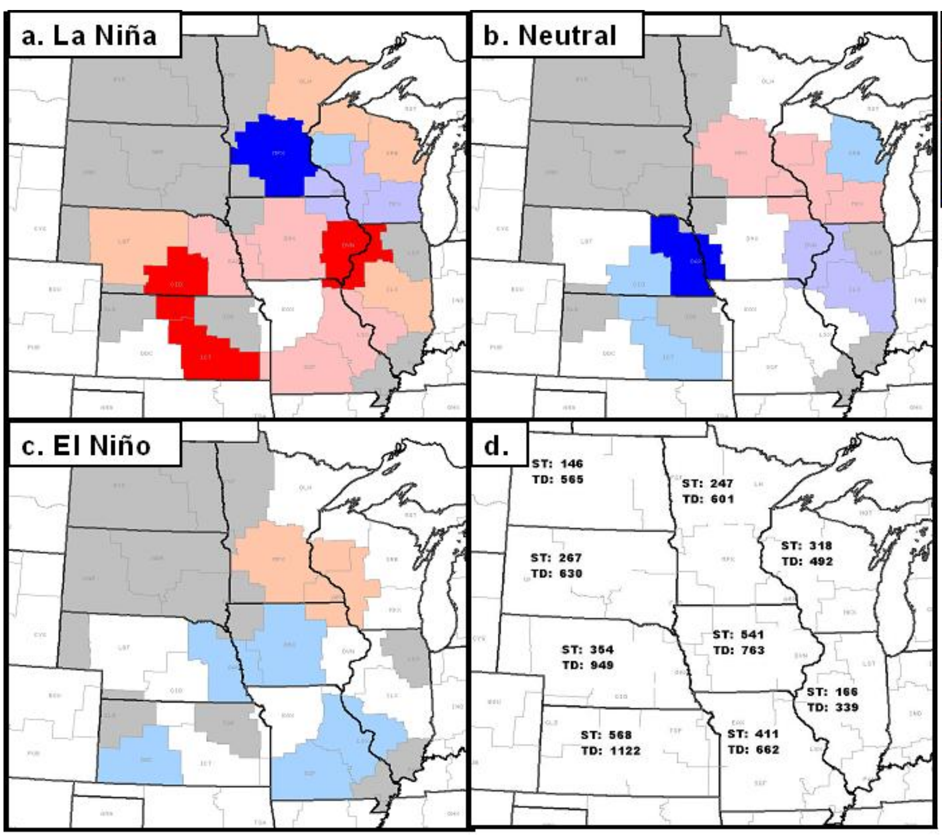
Initial results indicate many coherent signals in all phases of ENSO across the entire study area. Relationships of severe weather parameters to the ENSO phase were made from the prior year fall (beginning August-September-October of the prior year) through the late fall of the given year (September-October-November), with the purpose of investigating lagged relationships between ENSO phase and convective activity as well as concurrent impacts.

Results are typically found consistently in a given state or CWA during any one of three season: fall and winter of the prior year (August-September-October of the prior year through January-February-March), early spring of the convective year (February-March-April through April-May-June), and late spring/summer/early fall of the convective year (May-June-July through September-October-November). Due to the spring frailty of the ENSO phase, which is the tendency for ENSO phase to be more sensitive to change in April and May, those months tended to carry less of a statistical relationship to convective activity and often represented a shift in the type of impact within a given state or CWA. Many study areas demonstrated relationships in both the prior year fall/winter and the late spring/summer/fall, while others exhibited relationships in one or the other. Seldom did a state or CWA exhibit no relationship at all between ENSO phase and a given convective parameter. The results found in this study were consistent with several of the previous studies noted above, including Agee and Zurn-Birkhimer (1998), Bove (1998), Bove and O'Brien (1998), Browning (1998), and Etkin (2001).

A few examples of results uncovered by the study are presented below.

3.1 Late Spring/Summer/Fall

A wide swath of the study area demonstrated a tendency for enhanced tornado activity when a La Niña is occurring in the late spring/summer/fall of the concurrent convective year, with relationships to both the number of tornado days and the number of significant tornadoes (Figure 1). The impacted area includes much of Kansas and Nebraska into Missouri, Iowa, and Illinois. Statistically significant signals appeared consistently for either an enhanced probability of above normal activity or a diminished probability of below normal activity during a La Niña. The relationship was among the strongest observed in the study area for all ENSO phases and seasons for consistency among seasons as well as spatial consistency. Some of the CWAs within the region also exhibited diminished potential for tornado activity during either El Niño or neutral phases, including a signal for enhanced potential of below normal tornado activity during neutral years in



ST= Significant Tornadoes
TD= Tornado Days

Figure 1. Impacts on significant tornado (ST) and tornado day (TD) climatologies during the late spring, summer, and early fall of the concurrent convective year based on ENSO phase (a-c), with climatological values (d) for comparison. Gray areas indicate CWAs within the study area that have not been composited. White areas within the nine-state study area indicate no reliable signal.

eastern Iowa and Illinois as well as eastern Nebraska into eastern Kansas.

Conversely, in central Wisconsin and Minnesota, signals for diminished tornado activity during a La Niña appeared, as well as signals for enhanced potential for activity during either El Niño or neutral phases.

3.1 Prior Year Fall/Winter

While results were not as coherent as those for ENSO phases occurring during the heart of convective season, several significant signals did appear based on the ENSO phase of the fall and winter prior to the convective year (Figure 2). In the southwestern part of the study area, including parts of Kansas and Nebraska, signals indicate an enhanced probability of below normal tornado activity when an El Niño occurs during the preceding fall and winter. The signal also appears, though less spatially consistent, in parts of Minnesota, Wisconsin, and Missouri.

Relationships also appeared for the La Niña phase. In Minnesota and Wisconsin, signals appeared for enhanced potential of below normal tornado activity or diminished potential of above normal tornado activity when a La Niña occurs during the preceding fall and winter. Much of Nebraska and parts of Kansas exhibited signals for enhanced potential of above normal or diminished potential of below normal activity when a La Niña occurs in the preceding fall and winter, as well.

Many individual CWAs demonstrated statistically significant relationships across multiple seasons without coherent signals in neighboring areas, as well. The compositing analysis was created to determine relationships at the WFO scale, and due to smaller scale influences as well as the potential for smoothed or conflicting signals within neighboring CWAs, results within individual CWAs are not required to match neighboring CWAs for the results to be useful. For example, the North Platte, Nebraska (LBF) WFO exhibited an enhanced potential for an above normal number of significant tornadoes when a neutral conditions occur during the preceding fall and winter. Occurrences such as LBF demonstrate the benefit of the compositing methodology within a CWA in determining local scale statistical relationships to the ENSO phase.

4. CONCLUSIONS AND FUTURE WORK

While it is still too early to make conclusive comments, the results of this study do imply that there are statistically significant relationships between multiple severe weather parameters and ENSO phase in the north central United States. Results were attainable in

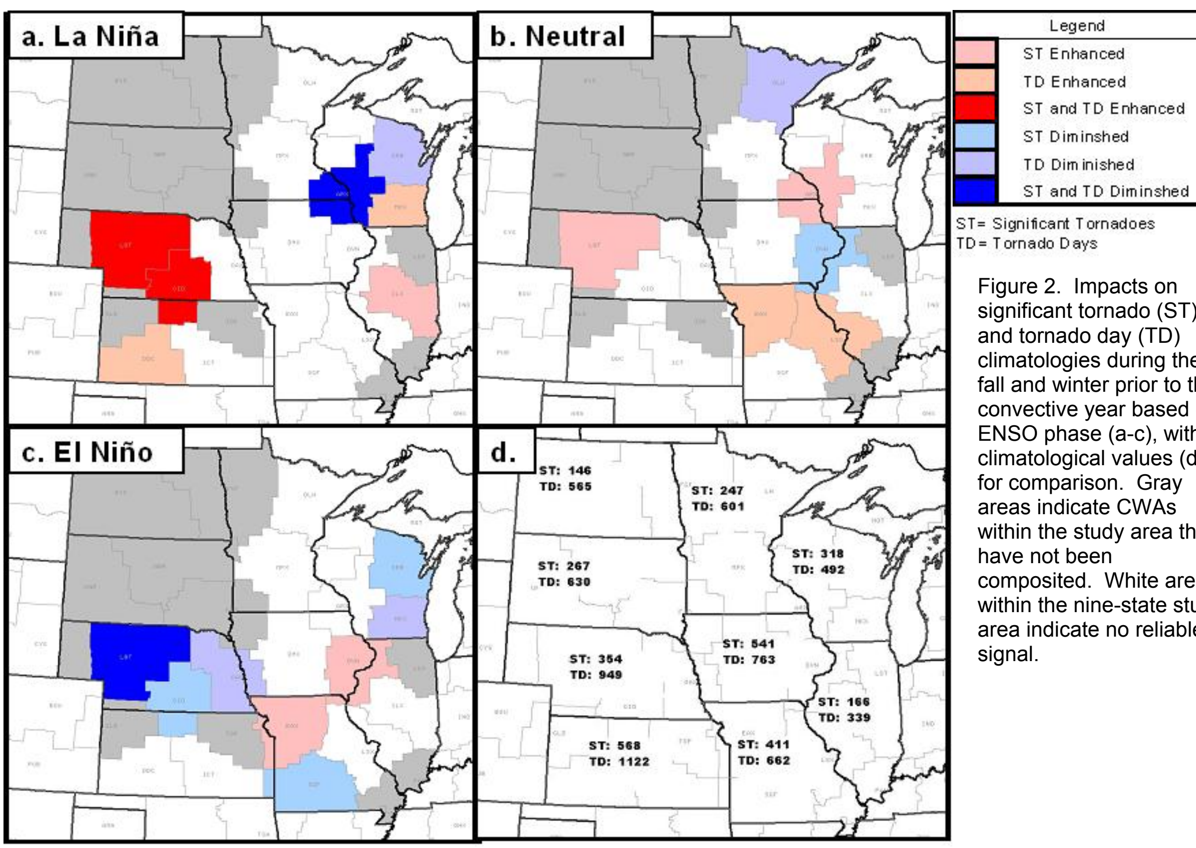


Figure 2. Impacts on significant tornado (ST) and tornado day (TD) climatologies during the fall and winter prior to the convective year based on ENSO phase (a-c), with climatological values (d) for comparison. Gray areas indicate CWAs within the study area that have not been composited. White areas within the nine-state study area indicate no reliable signal.

areas with a high number of severe weather events as well as those where severe weather occurrences are less frequent, indicating that the compositing methodology will be useful for severe weather parameters even in areas outside of the peak of severe weather activity.

Extensive future work will be required before broad conclusions can be drawn. The study will be expanded to include more severe weather parameters, and composites may be completed to compare activity within a season to the ENSO phase, rather than comparing yearly activity to the phase, to better determine temporal as well as spatial patterns in the relationship between ENSO and severe weather activity. Statistical results will need to be translated to synoptic pattern changes for given seasons and ENSO phases, as well, in order determine relationships between ENSO phase and anomalies in severe weather climatology in the north central United States.

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