Ongoing Research at AOML: Trans-Niño and Tornadoes

The severe weather database (SWD) from NOAA indicates that the number of total U.S. tornadoes (i.e., from F0 to F5 in Fujita-Pearson scale) during the most active tornado months of April and May (AM) has been steadily increasing since 1950 (Figure 1a). However, due to the improvements in tornado detection technology with time, one must be cautious in attributing this secular increase in the number of U.S. tornadoes to a specific long-term climate signal [Brooks and Doswell, 2001]. Since intense and long-lived tornadoes are much more likely to be detected and reported even before a national network of Doppler radar was build in the 1990s, the number of intense U.S. tornadoes (i.e., from F3 to F5 in Fujita-Pearson scale) in AM during 1950-2010 is used (Figure 1b), after detrending, as the primary diagnostic index (Figure 1c).

In the central U.S. east of the Rocky Mountains, cold and dry upper-level air from the high latitudes often converges with warm and moist lower-level air coming from the Gulf of Mexico (GoM). Due to this so-called large-scale differential advection (i.e., two or more different air masses converging at different heights), a conditionally unstable atmosphere with high convective available potential energy is formed that causes frequent and intense thunderstorms. With the addition of a triggering mechanism, such as the horizontal spinning effect provided by the lower-level wind shear (i.e., wind speed increasing or wind direction changing with height), these thunderstorms can spawn intense tornadoes. Consistently, the moisture transport from the GoM to the central U.S. is significantly correlated with the number of intense U.S. tornadoes in AM (see Table 1).

The Pacific – North American (PNA) pattern in boreal winter and spring is linked to the large-scale differential advection in the central U.S. as discussed in earlier studies [e.g., Munoz and Enfield, 2011]. During a negative phase of the PNA, an anomalous cyclone is formed over North America that bring cold and dry upper-level air from the high latitudes to the central U.S., and an anticyclone is formed over the southeastern seaboard that increases the southwesterly wind from the GoM to the central U.S., thus enhancing the Gulf-to-U.S. moisture transport. Although the PNA is a naturally occurring atmospheric phenomenon driven by the intrinsic variability of the atmosphere, a La Niña in the tropical Pacific can project onto a negative phase PNA pattern [e.g., Lau 1981; Wallace and Gutzler 1981; Straus and Shukla 2002]. In addition, since the Gulf-to-

U.S. moisture transport can be enhanced with a warmer GoM, the sea surface temperature (SST) anomaly in the GoM can also affect U.S. tornado activity. During the decay phase of a La Niña in spring, the GoM is typically warmer than usual [e.g., Alexander and Scott 2002]. Therefore, the Gulf-to-U.S. moisture transport can be increased during the decay phase of a La Niña in spring due to the increased SSTs in the GoM and the strengthening of the southwesterly wind from the GoM to U.S. Nevertheless, none of these (i.e., PNA, GoM SST, and La Nina) are significantly correlated with the number of intense tornadoes in AM (see Table 1), consistent with previous studies [e.g., Cook and Schaefer, 2008]. Currently, seasonal forecast skill for intense U.S. tornado outbreaks, such as occurred in 2011, has not been demonstrated.

Among the long-term climate patterns considered in Table 1, only the Trans-Niño (TNI) Index is significantly correlated (r = 0.33) with the number of intense U.S. tornadoes in AM. The TNI, which is defined as the difference between the normalized SST anomalies in Niño-1+2 (10S° - 0°; 90°W - 80°W) and Niño-4 (5°N - 5°S; 160°E - 150°W) regions, represents the evolution of the El Niño-Southern Oscillation (ENSO) in the months leading up to the event and the subsequent evolution with opposite sign after the event [Trenberth and Stepaniak, 2001]. Given that AM is typically characterized with the development or decay phase of ENSO events, it is more likely that the tropical Pacific SST anomalies in AM are better represented by the TNI index than the conventional ENSO indices such as Niño-3.4 (5°N - 5°S; 170°W - 120°W) or Niño-3 (5°N - 5°S; 150°W-90°W). Nevertheless, it is not at all clear why the number of intense U.S. tornadoes in AM is significantly correlated with the TNI index, but not with other ENSO indices. This is the central question that scientists at NOAA AOML and the University of Miami are currently exploring using both observations and an atmospheric general circulation model [Lee et al. 2011].

To further explore the potential link between the TNI and U.S. tornado activity, the years from 1950 to 2010 (61 years in total) are ranked based on the number of intense U.S. tornadoes in AM. The top ten years are characterized by increased Gulf-to-U.S. moisture transport in the lower-level and an upper-level cyclone over North America that advects cold and dry air to the central U.S [Lee et al., 2011]. As shown in Table 2, among the top ten years, seven years including the top three are identified with a positive phase (i.e., above ¼ quantile) TNI index (i.e., normalized SST anomalies are larger in the Niño-1+2 than in Niño-4 region). Five out of those seven years are characterized by a La Niña transitioning to a different phase or persisting beyond AM (1957, 1965, 1974, 1999, and 2008) and the other two with an El Niño transitioning to either a La Nina or neutral phase (1983 and 1998). Figure 2a shows the composite SSTs for those five positive phase TNI years transitioning from a La Niña.

On the other hand, among the bottom ten years, only one year is identified with a positive phase TNI, and the other nine years are with a neutral phase (i.e., between ¼ and ¾ quantile) TNI (see Table 3), suggesting that a negative phase of the TNI does not decrease or increase the number of intense U.S. tornadoes in AM. Interestingly, four years among the bottom ten years are identified with a La Niña transitioning to a different phase or persisting beyond AM (1950, 1951, 1955 and 2001), and four are with an El Niño transitioning to a different phase or persisting beyond AM (1958, 1987, 1988 and 1992). As shown in Figure 2b, the SST anomaly pattern for the four years with a La Niña transitioning is that of a typical La Niña with the SST anomalies in the Niño-4 and Niño-1+2 being both strongly negative (i.e., neutral phase TNI). Similarly, as shown in Figure 2c, the SST anomaly pattern for the four years with an El Niño transitioning is that of a typical El Niño with the SST anomalies in the Niño-4 and Niño-1+2 being both strongly positive (i.e., neutral phase TNI).

In summary, observations indicate that a positive phase of the TNI (i.e., normalized SST anomalies are larger in Niño-1+2 than in Niño-4 region) is linked to increased number of intense U.S. tornadoes in AM, whereas both La Niñas and El Niños with a neutral phase of the TNI (i.e., the SST anomalies in the Niño-1+2 region are as strong and the same sign as the SST anomalies in the Niño-4) are linked to a decreased number of intense U.S. tornadoes in AM. According to a research article submitted to Geophysical Research Letters [Lee et al., 2011], during a positive phase of the TNI, the warming in the eastern tropical Pacific increases convection locally, but also contributes to suppressing convection in the central tropical Pacific. This in turn works constructively with cooling in the central tropical Pacific to force a strong and persistent negative phase PNA-like teleconnection pattern. The anomalous winds that are associated with this teleconnection pattern bring more cold and dry upper-level air from the high-latitudes and more warm and moist lower-level air from the Gulf of Mexico converging into the central U.S., and thus provide a favorable condition for increased U.S. tornado activity. This appears to be the case for spring of 2011. Model experiments further suggest that the warming in western pacific, which is a distinctive feature in the TNI event in 2011, suppresses convection in the central Pacific, and thus works constructively with the cooling in the central Pacific to force a strong and persistent negative phase PNA-like pattern [Lee et al. 2011].

Table 1. Correlation coefficients of various long-term climate patterns with the number of intense (F3 - F5) tornados in April and May (AM) during 1950-2010. All indices including the tornado index are detrended. The SWD, ERSST3, and NCEP-NCAR reanalysis are used to obtain the long-term climate indices used in this table. Any correlation value with above the 95% significance is in bold[a]

Index	DJF	FMA	AM
Gulf-to-U.S. moisture transport	0.08	0.20	**0.40**
GoM SST	0.15	0.21	0.20
Niño-4	-0.22	-0.20	-0.19
Niño-3.4	-0.13	-0.13	-0.11
Niño-1+2	0.02	0.11	0.15
TNI	**0.28**	**0.29**	**0.33**
PNA	-0.05	-0.10	-0.20
PDO	-0.12	-0.10	-0.14
NAO	-0.01	-0.10	-0.18

[a] The Gulf-to-U.S. meridional moisture transport is obtained by averaging the vertically integrated moisture transport in the region of 25°N - 35°N and 100°W - 90°W. The North Atlantic Oscillation (NAO) index is defined as the first leading mode of Rotated Empirical Orthogonal Function (REOF) analysis of monthly mean 500 hPa. The Pacific Decadal Oscillation (PDO) is the leading principal component of monthly SST anomalies in the North Pacific Ocean north of 20°N. The Pacific - North American (PNA) pattern is defined as the second leading mode of REOF analysis of monthly mean 500 hPa.

Table 2. The total of 61 years from 1950 to 2010 are ranked based on the detrended number of intense U.S. tornadoes in AM. The top ten most active U.S. tornado years are listed with ENSO phase in spring and TNI index in AM for each year. Strongly positive (above ¼ quantile) and negative (below ¾ quantile) TNI index values are in bold and italic, respectively.

Ranking	Year	ENSO phase in spring	TNI index (detrended)
1	1974	La Niña persists	**1.30 (1.48)**
2	1965	La Niña transitions to El Niño	**1.39 (1.54)**
3	1957	La Niña transitions to El Niño	**0.57 (0.69)**
4	1982	El Niño develops	*-1.11* (*-0.89*)
5	1973	El Niño transitions to La Niña	-0.42 (-0.24)
6	1999	La Niña persists	**0.47 (0.75)**
7	1983	El Niño decays	**1.86 (2.08)**
8	2003	El Niño decays	*-1.24* (*-0.94*)
9	2008	La Niña decays	**1.41 (1.73)**
10	1998	El Niño transitions to La Niña	**1.69 (1.97)**

Table 3. The total of 61 years from 1950 to 2010 are ranked based on the detrended number of intense U.S. tornadoes in AM. The bottom ten years are listed with ENSO phase in spring and TNI index in AM for each year. Strongly positive (above ¼ quantile) and negative (below ¾ quantile) TNI index values are in bold and italic, respectively.

Ranking	Year	ENSO phase in spring	TNI index (detrended)
52	1958	El Niño decays	-0.61 (-0.49)
53	1955	La Niña persists	-0.27 (-0.16)
54	2001	La Niña decays	0.21 (0.50)
55	1986	El Niño develops	-0.39 (-0.16)
56	1988	El Niño transitions to La Niña	-0.37 (-0.13)
57	1987	El Niño persists	0.10 (0.34)
58	1992	El Niño decays	0.21 (0.47)
59	1952	Neutral	-0.67 (-0.57)
60	1951	La Niña transitions to El Niño	-0.31 (-0.22)
61	1950	La Niña persists	**0.77 (0.86**)

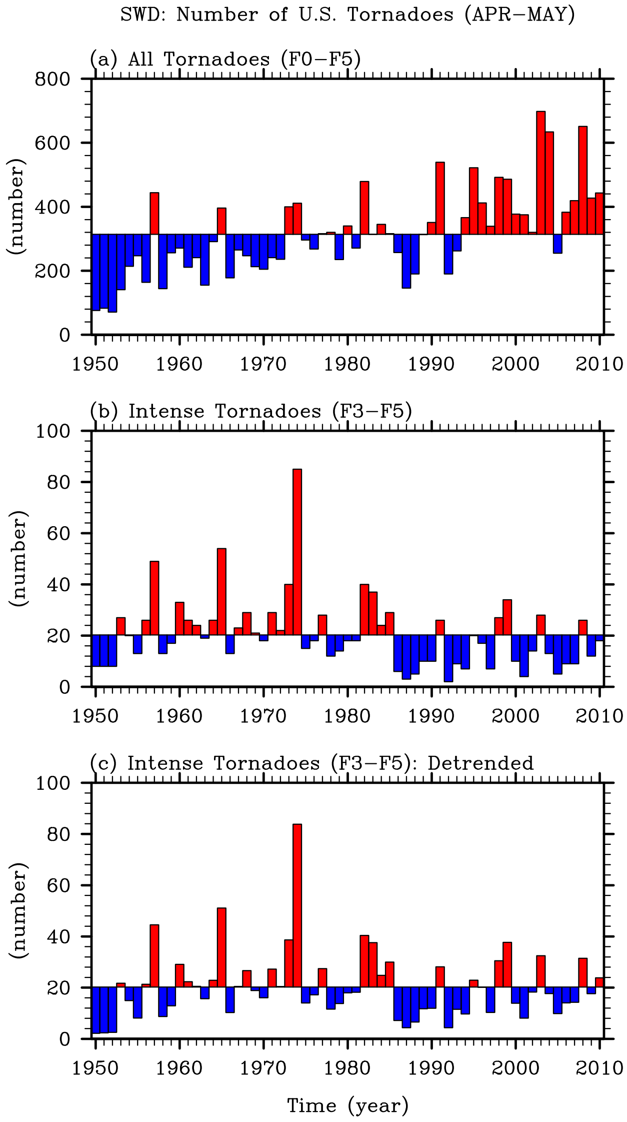

Figure 1. The number of (a) total (F0 – F5) and (b) intense (F3 – F5) US tornadoes for the most active tornado months of April and May (AM) during 1950-2010 obtained from SWD. The detrended number of intense U.S. tornadoes in AM, which is the primary diagnostic index used in this study, is shown in (c).

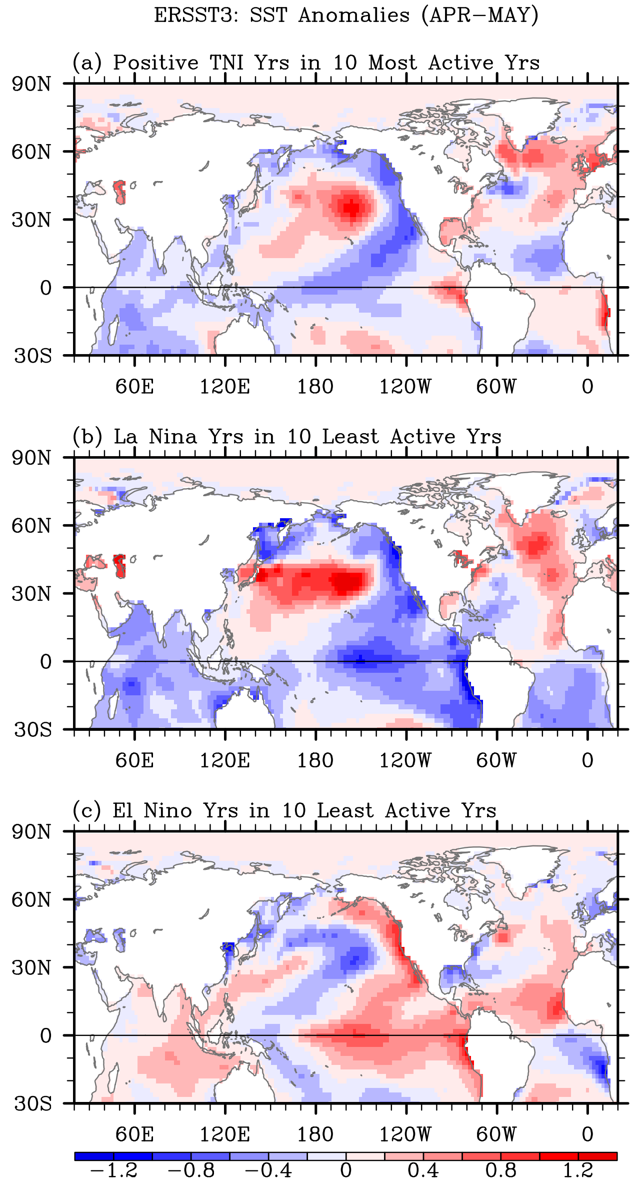

Figure 2. Composite SST anomalies in AM, obtained from ERSST3, for (a) the five positive TNI years transitioning from a La Niña identified among the 10 most active U.S. tornado years in AM during 1950-2010, and for (b) the four years with a La Niña transitioning and (c) the four years with an El Niño transitioning identified among the 10 least active U.S. tornado years in AM during 1950-2010.

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