ENSO phase transition in spring and its potential impact on tornado outbreaks in the U.S

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Outline

- Motivation and Background
- Trans-Niño and U.S. Tornado Activity
- Model Experiments
- Summary

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In April and May of 2011, a record breaking 1,084 tornadoes and 541 tornado-related fatalities were confirmed in the U.S.

2011 (541) was one of the four deadliest tornado years in the U.S. history along with 1925 (794), 1936 (552) and 1917 (551).

Questions were raised as to whether the extreme tornadoes outbreaks could be linked to long-term climate variability.
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.

Due to this **large-scale differential advection**, a conditionally unstable atmosphere with high CAPE is formed. The associated lower-level vertical shear further provides a favorable environment to form an intense rotating thunderstorm known as a supercell.
### U.S. Tornado Activity and Climate Indices

<table>
<thead>
<tr>
<th>Index</th>
<th>DJF</th>
<th>FMA</th>
<th>AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>GoM-to-U.S. moisture transport</td>
<td>0.12 (0.09)</td>
<td>0.20 (0.10)</td>
<td><strong>0.44 (0.34)</strong></td>
</tr>
<tr>
<td>Lower-Level vertical wind shear</td>
<td>0.12 (0.09)</td>
<td>0.20 (0.12)</td>
<td><strong>0.44 (0.35)</strong></td>
</tr>
<tr>
<td>GoM SST</td>
<td>0.15 (0.15)</td>
<td>0.21 (0.16)</td>
<td>0.20 (0.19)</td>
</tr>
<tr>
<td>Niño-4</td>
<td>-0.22 (-0.19)</td>
<td>-0.20 (-0.18)</td>
<td>-0.19 (-0.18)</td>
</tr>
<tr>
<td>Niño-3.4</td>
<td>-0.13 (-0.11)</td>
<td>-0.13 (-0.12)</td>
<td>-0.11 (-0.11)</td>
</tr>
<tr>
<td>Niño-1+2</td>
<td>0.02 (0.03)</td>
<td>0.11 (0.11)</td>
<td>0.15 (0.13)</td>
</tr>
<tr>
<td>TNI</td>
<td><strong>0.28 (0.26)</strong></td>
<td><strong>0.29 (0.28)</strong></td>
<td><strong>0.33 (0.29)</strong></td>
</tr>
<tr>
<td>PNA</td>
<td>-0.05 (-0.02)</td>
<td>-0.10 (-0.06)</td>
<td>-0.20 (-0.16)</td>
</tr>
<tr>
<td>PDO</td>
<td>-0.12 (-0.09)</td>
<td>-0.10 (-0.11)</td>
<td>-0.14 (-0.20)</td>
</tr>
<tr>
<td>NAO</td>
<td>-0.01 (-0.07)</td>
<td>-0.10 (-0.14)</td>
<td>-0.18 (-0.18)</td>
</tr>
</tbody>
</table>

- Correlation coefficients of various long-term climate patterns with the number of intense (F3-F5) tornadoes during the most active tornado months of April and May (AM)
- Niño–3.4 has a very weak correlation with U.S. Tornado activity, consistent with previous studies.
- Niño–4 is negatively correlated, while Niño-1+2 is positively correlated.
- U.S. tornado activity is more strongly correlated with Trans-Niño (TNI) than any other climate pattern.
What is Trans-Niño (TNI)?

- **Correlation between TNI and SST anomalies during 1977-2000**

  - TNI is defined as the difference in normalized SST anomalies between the Niño-1+2 and Niño-4 regions [Trenberth and Stepaniak, 2001].

  - It represents the evolution of ENSO during its onset and decaying phases, which frequently occur in boreal spring.

- **Correlation between Niño-3.4 and SST anomalies during 1977-2000**

  - Why is the number of intense U.S. tornadoes in AM significantly correlated with the TNI index, but not with conventional ENSO?
A positive TNI typically occurs during the decay phase of La Niña.

But, it can also occur during the onset phase of El Niño.

But, such a case has rarely occurred since 1980s [McPhaden and Zhang 2009].

# Trans-Niño and U.S. Tornado Activity

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

- However, correlation analysis may not be so useful.
- Top 10 extreme tornado outbreak years during 1950-2010 are listed in the table.
- 7 out of the top 10 extreme tornado years are identified with positive phase (within the upper quartile) TNI.
- The top 3 years (1974, 1965 and 1957) are also identified with positive phase (within the upper quartile) TNI.
- The 10 least active tornado years are largely neutral TNI years (not shown).
Key Atmos. Conditions for U.S. Tornado Outbreaks

- Anomalous upper-level cyclone over the North America brings more cold and dry upper-level air to the east of the Rockies.
- Increased GoM-to-U.S. lower-level wind (i.e., GPLLLJ) and associated moisture transport.
- Enhanced large-scale differential advection leads to increased CAPE and vertical wind shear east of the Rockies.
Trans-Niño and U.S. Tornado Activity

- Key atmospheric conditions for the top 10 positive TNI years are shown.
- Anomalous upper-level cyclone over the North America brings more cold and dry upper-level air to the east of the Rockies.
- Increased GoM-to-U.S. lower-level wind (i.e., GPLLLJ) and associated moisture transport.
- Enhanced large-scale differential advection leads to increased CAPE and vertical wind shear east of the Rockies.
- All these conditions are consistent with those for the top 10 extreme tornado outbreak years.
Trans-Niño and U.S. Tornado Activity

- SST anomalies for 5 positive TNI years identified among the 10 most active tornado years are shown in the upper panel.
- SST anomalies for 10 positive TNI years and for the 10 most active tornado years are shown in the middle and upper panels.
- Positive Trans-Niño occurs when normalized SST anomalies are larger in Niño-1+2 than in Niño–4 region [Trenberth and Stepaniak 2001].
- Therefore, neutral Niño–4 with positive Niño–1+2 and neutral Niño–1+2 with negative Niño–4 are also qualified as positive TNI conditions.
The same methodology was previously used in Lee et al. [2008] for studying ENSO teleconnection to the tropical North Atlantic region.
Model Experiments (CAM3-SOM)

- Key atmospheric conditions for EXP_TNI are shown.
- Anomalous upper-level cyclone over the North America brings more cold and dry upper-level air to the east of the Rockies.
- Increased GoM-to-U.S. lower-level wind and associated moisture transport.
- All these conditions are consistent with the observations.
Model Experiments (CAM3-SOM)

- **EXP_CPC**: Same as EXP_TNI except that SST anomalies in EP are kept neutral.
- **EXP_EPW**: Same as EXP_TNI except that SST anomalies in the CP are kept neutral.
- In both cases, all three conditions are favorable for increased U.S. tornado activity.
- Why EXP_CPC and EXP_EPW have a similar influence on the U.S?
As shown in earlier theoretical studies, the background vertical wind shear is one of the two critical factors required for tropical heating to radiate barotropic teleconnections to the high-latitudes [e.g., Webster 1981; Kasahara and da Silva Dias 1986; Lee et al. 2009].

The so-called Rossby wave source term for the barotropic vorticity equation (linearized with background mean flow) is determined by the background vertical wind shear.
Background Wind Shear & Teleconnection

- Two-level model of Lee et al. [2009], linearized with an idealized background flow in AM, is forced with cooling in CP.
- PNA-like teleconnection pattern emanates from CP to enhance the large-scale differential advection in the central U.S.
- When the background shear is decreased by 75%, while the background barotropic wind is kept the same, the PNA-like teleconnection pattern almost disappears.
- See Lee et al. [2009] and references therein for more discussions on this issue.
In both observations and EXP_CLM, the background vertical wind shear between 200 and 850hPa in AM is largest in the central tropical North Pacific and smallest in EP and the western tropical Pacific (WP).

The spatial pattern of the background wind shear in the tropical Pacific suggests that the Rossby wave train in EXP_EPW is not directly forced in EP.

What forced the Rossby wave train in EXP_EPW?
In EXP_EPW, convection is increased locally in EP, but it is decreased in CP as in EXP_CPC.

Increased convection in EP suppresses convection in CP that in turn forces a negative phase PNA-like pattern.

Cooling in CP and warming in EP may have a constructive influence on the teleconnection pattern.

Perhaps, reduced convection in the CP can be explained as Rossby wave response to warm SST anomalies in the EP [Gill 1980].

Cooling in CP with neutral SST anomalies in EP or warming in EP with neutral SST anomalies in CP can strengthen the large-scale differential advection over the central U.S.
Summary

● Observations and reanalysis products are used to show that a positive phase of the Trans-Niño is linked to U.S. tornado outbreaks.

● The link between the Trans-Niño and U.S. tornado outbreaks is due to the enhanced large-scale differential advection during a positive phase of the Trans-Niño:
  1) anomalous upper-level cyclone over the North America;
  2) increased GoM-to-U.S. moisture transport;
  3) increased lower-level vertical wind shear east of the Rockies.

● Modeling experiments suggest that warm SST anomalies in the EP work constructively with cold SST anomalies in the CP to force a strong and persistent teleconnection pattern that enhances large-scale differential advection.

Extra Slides from Here
Global Map of Tornado Frequency

- Tornadoes are more common in the U.S. than in any other country in the world.
- During the last two decades, 938 ~ 1820 tornadoes have occurred in the U.S. annually.
Is U.S Tornado Activity Increasing?

- The number of total U.S. tornadoes (F0-F5) during the most active tornado months of April and May (AM) has been steadily increasing since 1950.
- However, tornado database, especially in earlier periods, has many issues.
- Once F0 tornadoes are removed, the positive trend disappears.
- 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.
- Here, we use the number of intense U.S. tornadoes (F3-F5) in AM as the primary diagnostic index in this study.
- Intense tornado-days is also used as an index.
Trans-Niño and U.S. Tornado Activity

- Incidents of intense (F3-F5) tornadoes for 10 positive, 10 neutral and 10 negative Trans-Niño years during 1950-2010 are shown.

- Number of intense tornadoes is increased from 168 during the 10 neutral TNI years to 304 during the 10 positive TNI years (it is almost doubled).

- During positive TNI years, violent (F4-F5) tornadoes are increased over the Ohio river valley.

- During negative TNI years, number of intense tornadoes is not increased.
Trans-Niño and Historical U.S. Tornado Outbreaks

- Tri-state (Missouri, Illinois and Indiana) tornado of March 18, 1925 is the deadliest tornado outbreak event in the U.S. history (695 deaths).
- Super tornado outbreak on April 3, 1974 resulted in 315 deaths.
- April 25-28, 2011 is the 2nd deadliest tornado outbreak event (346 deaths).
- 1936 (552) and 1917 (551) are the 2nd and 3rd deadliest tornado years.
- All five of these historic tornado outbreak years were positive Trans-Niño years.
- April & March of 1917 is marked as the strongest TNI during the period of 1854 – 2011 (not shown).
Trans-Niño and Historical U.S. Tornado Outbreaks

- All three conditions are consistent with those for the 10 positive Trans-Niño years.
- This means that the positive Trans-Niño condition during these historical tornado outbreak years are not just coincident.
- Therefore, it is likely that the positive Trans-Niño condition have contributed to these historical tornado outbreak events.
Prior to 1976/77, a positive TNI could occur during the onset of an El Niño and the decay of a La Niña.

After 1976/77, a positive TNI occurs only during the decay phase of a La Niña.

Reproduced from McPhaden and Zhang [2009]
In general, CFSRR can simulate slower decay of SST anomalies in CP and faster decay in EP during the decay phase of La Niña.

This tends to deteriorate when the model is initialized in December (0) and January (+1).
Impacts of CPC versus EPW on Teleconnection

- Multiple regression coefficients of key atmospheric conditions on WP, CP and EP SST anomalies.
- Cold SST anomalies & warm SST anomalies in the EP have somewhat similar effects.
Model Experiments (CAM3-SOM)

- Results from EXP_TN1 and EXP_TN2 are shown.
- EXP_TN1: Tropical Pacific SSTs are prescribed with the composite of 10 positive TNI years.
- EXP_TN2: Tropical Pacific SSTs are prescribed with the composite of 10 most active years.
- All three conditions are favorable for increased U.S. tornado activity.
Impacts of CPC versus EPW on Teleconnection
### What is Fujita Scale?

The Fujita tornado scale (F scale) pegged to damage-causing winds speeds. The extent of damage expressed by the damage scale (f scale) varies with both windspeed and the strength of structures.

<table>
<thead>
<tr>
<th>Damage f scale</th>
<th>Little Damage</th>
<th>Minor Damage</th>
<th>Roof Gone</th>
<th>Walls Collapse</th>
<th>Blown Down</th>
<th>Blown Away</th>
</tr>
</thead>
<tbody>
<tr>
<td>f0</td>
<td>f1</td>
<td>f2</td>
<td>f3</td>
<td>f4</td>
<td>f5</td>
<td>f5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Windspeed F scale</th>
<th>F0</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 m/s</td>
<td>40 mph</td>
<td>73</td>
<td>113</td>
<td>158</td>
<td>207</td>
<td>261</td>
</tr>
</tbody>
</table>

To convert f scale into F scale, add the appropriate number:

- **Weak Outbuilding**
  - -3: f3 f4 f5 f5 f5 f5 f5
- **Strong Outbuilding**
  - -2: f2 f3 f4 f5 f5 f5 f5
- **Weak Framehouse**
  - -1: f1 f2 f3 f4 f5 f5 f5
- **Strong Framehouse**
  - 0: f0 f1 f2 f3 f4 f5 f5
- **Brick Structure**
  - +1: - f0 f1 f2 f3 f4
- **Concrete Building**
  - +2: - - f0 f1 f2 f3