Springtime ENSO phase evolution and U.S. tornado outbreaks

Can we predict extreme U.S. tornado outbreaks beyond the "weather" time scale?






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AOML Program Review

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U.S. tornado outbreaks in 2011

April 27, 2011 Tuscaloosa, Alabama

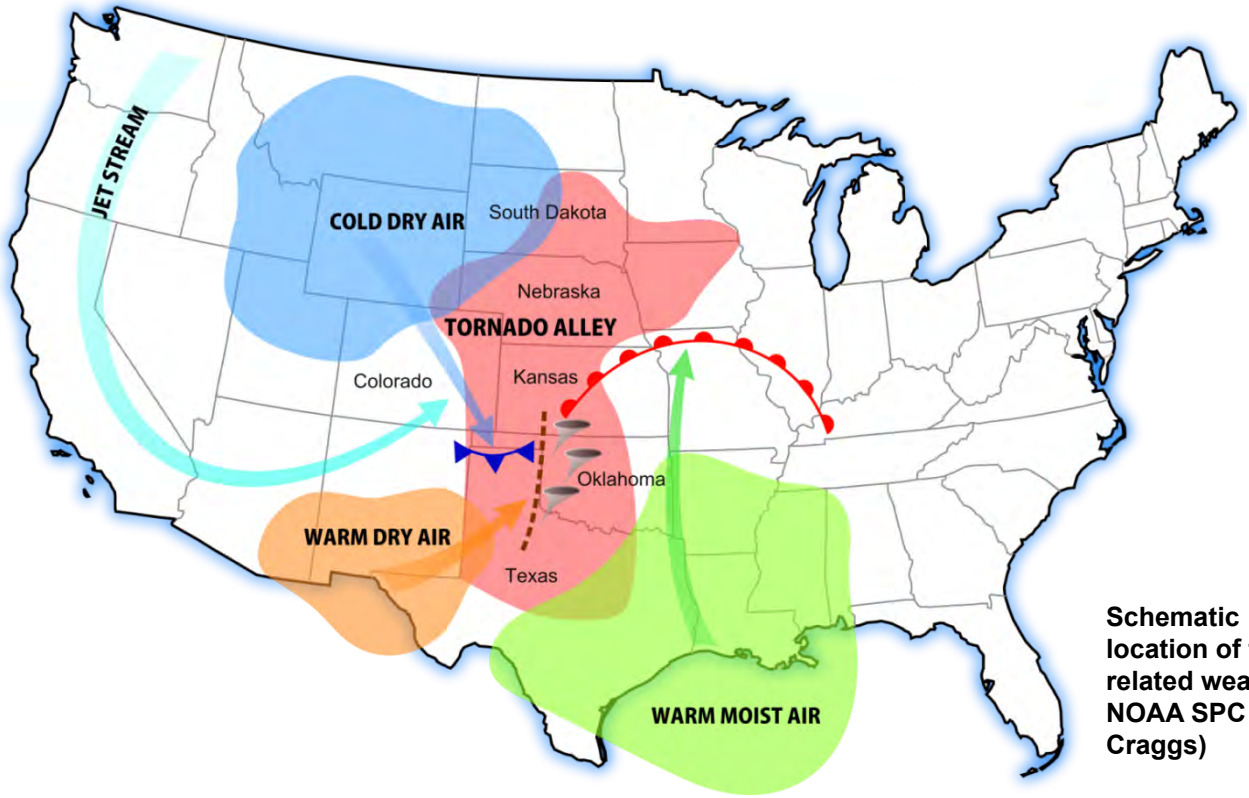
April 29, 2011 Tuscaloosa, Alabama

- April and May of 2011, a record breaking 1,084 tornadoes occurred in the U.S. with 541 fatalities
- 2011, one of the four deadliest tornado years in the U.S history along with 1925, 1936 and 1917

Needs for research & how AOML responded

- Can we predict extreme U.S. tornado outbreaks beyond the “weather” time scale?
- There is a need for research to identify a slowly varying climate process that is linked to U.S. tornado outbreaks and is potentially predictable
- NOAA CPC director (Wayne Higgins) requested NOAA labs to explore a potential link between 2010-2011 La Niña event and April-May 2011 U.S. tornado outbreak
- NOAA labs, including AOML and ESRL, responded to the request
- AOML’s contribution was published in the Journal of Climate (Lee et al. 2013) and highlighted in BAMS

Springtime atmospheric conditions in U.S.



Schematic diagram of the location of tornado alley and the related weather systems from NOAA SPC (Art work by Dan Craggs)

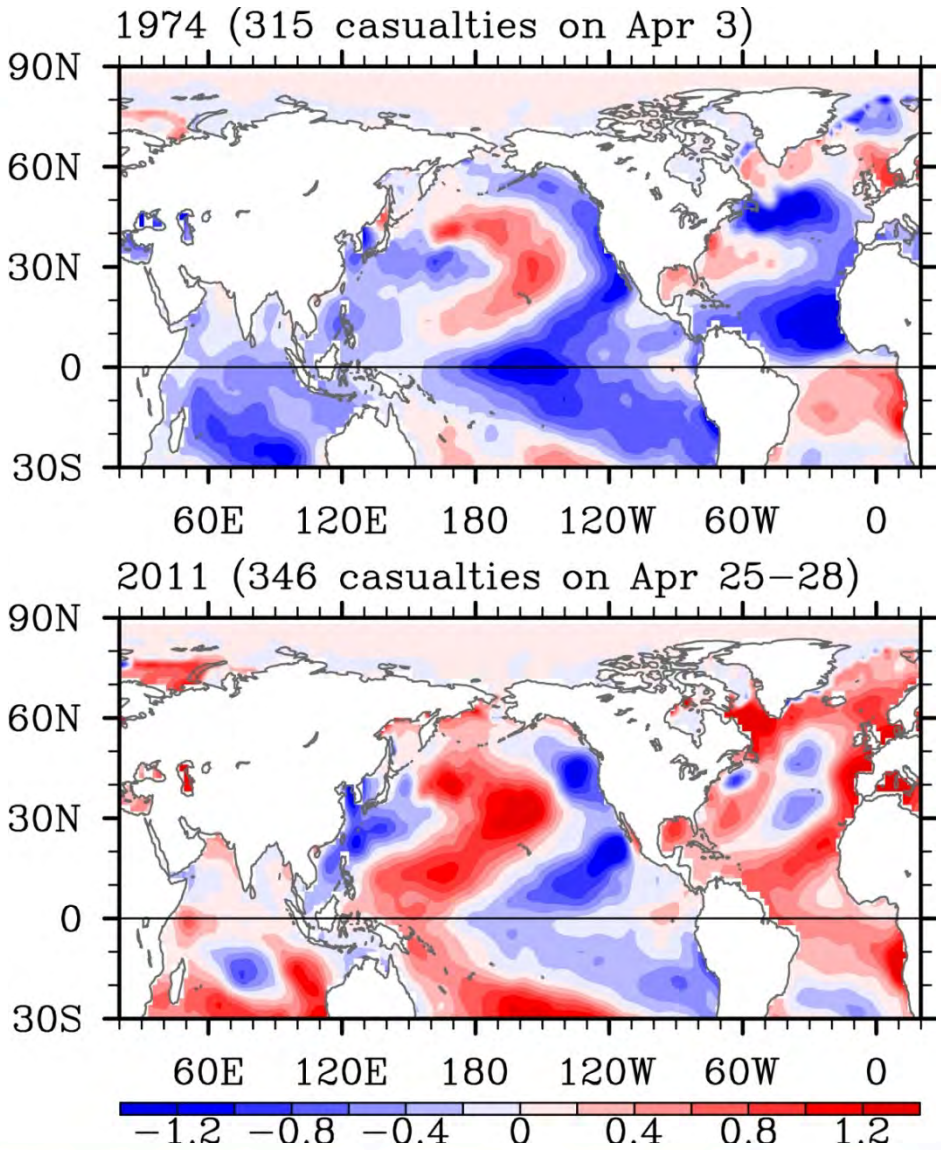
- Over the central U.S. in spring, cold & dry upper-level air collides with warm & moist lower-level air
- CAPE & lower-level shear provide favorable condition to form a supercell, linked to tornado genesis

U.S. tornado activity and climate indices

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

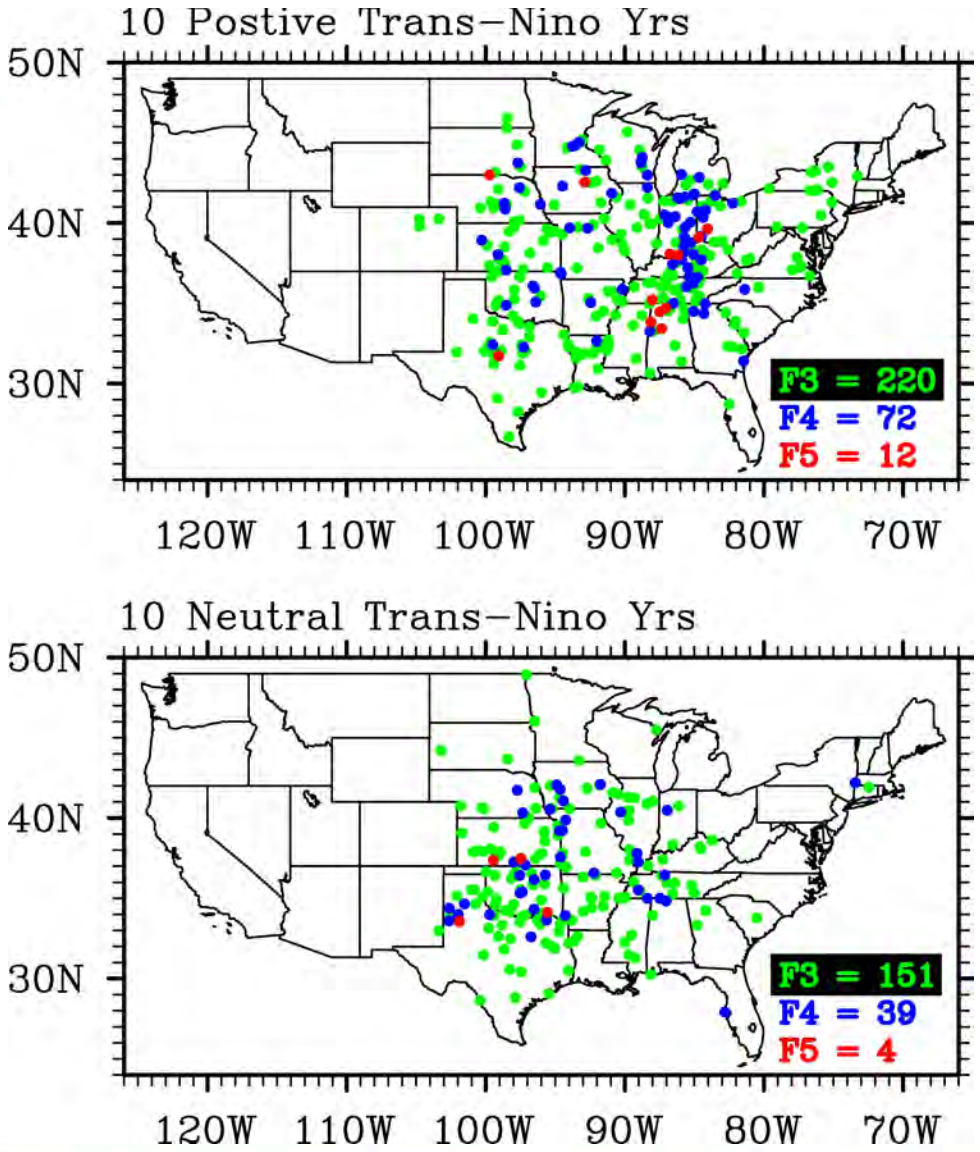
- Traditional ENSO indices (ex: Niño-3.4 & Niño 1+2) are not correlated with U.S. tornado activity in spring season
- U.S. tornado activity is significantly correlated with Trans-Niño index
- No other climate index is significantly correlated with U.S. tornado activity

What is Trans-Niño?



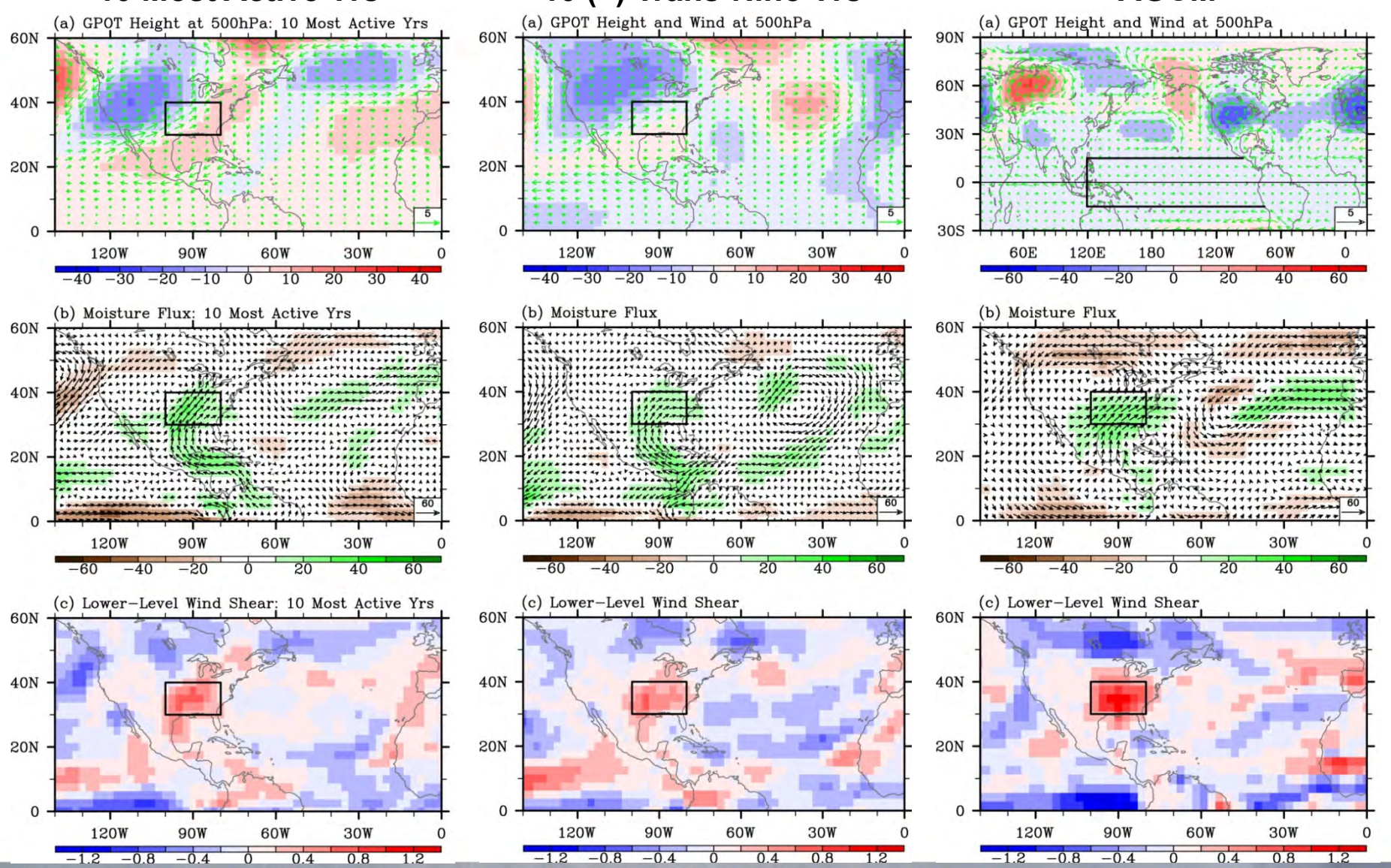
- **Trans-Niño index: zonal gradient of SST anomalies along the equatorial Pacific between central & eastern tropical Pacific**
- **(+) Trans-Niño typically occurs during the decay phase of La Niña**
- **Five historic tornado outbreak years (1917, 1925, 1936, 1974 and 2011) were all (+) Trans-Niño years**

Trans-Niño and U.S. Tornado activity



- **The number of intense (F3 - F5) tornadoes nearly doubles during a (+) Trans-Niño**
- **7 out of 10 extreme U.S. tornado outbreaks (including the top 3) during 1951 - 2010 associated with a (+) Trans-Niño**

Large-scale atmospheric conditions conducive for U.S. tornado outbreaks



Lee et al. (2013)

Toward developing a seasonal outlook for the occurrence of U.S. tornado outbreaks

- AOML & CPC partnership project funded by NOAA Climate Program Office

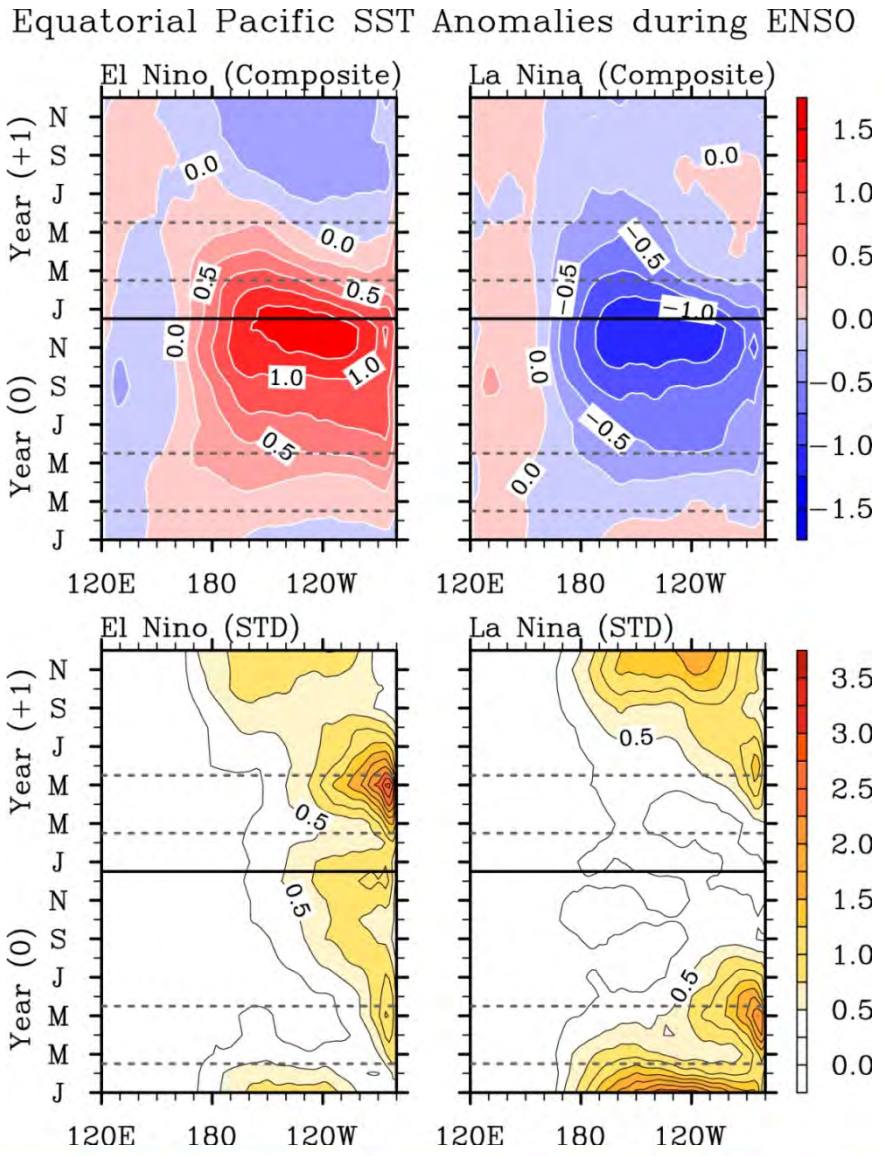
- Ultimate goal to develop a seasonal outlook for the occurrence of major U.S. tornado outbreaks

  1. Explore and build theoretical and observational basis for springtime ENSO phase evolution and its teleconnection to the U.S.

  2. Evaluate and improve the currently existing seasonal forecast systems focusing on CFSv2

  3. Explore an experimental hybrid dynamical-statistical seasonal forecasting system

Springtime ENSO phase evolution



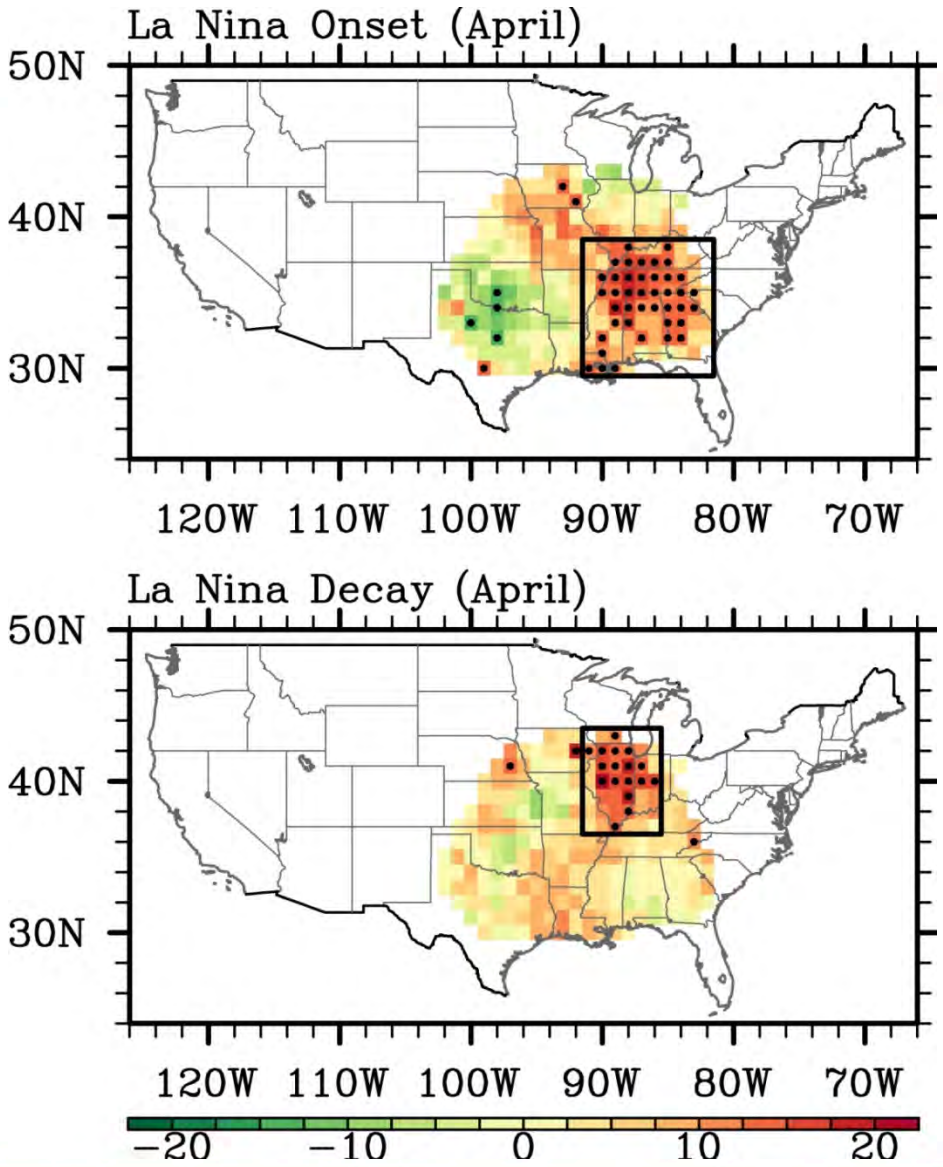
- **Equatorial Pacific ENSO SST anomalies weaker and less coherent in spring than in winter**
- **SST anomalies in the central tropical Pacific relatively persistent and consistent between ENSO events in spring**
- **Coherent springtime ENSO SST anomalies in the central tropical Pacific excite ENSO teleconnection to the U.S.**

Probability of regional tornado outbreak

- **# of tornadoes is not an effective index of tornado activity - a handful of outbreak years dominates the time series data**
- **Probability that the number of tornadoes in a predefined region exceeds the regional climatological mean + STD**

1. Count # of F1-F5 tornadoes for 1×1 grid boxes for each month and year
2. For each point, month and year, find the regional maximum # within a circle of 3°radius
3. Identify whether the regional maximum # exceeds the regional mean + STD
4. For a subset of data, count the number of outbreak years and perform Chi-square test of 90% significance

La Niña and U.S. tornado activity in April



- **La Niña onset phase: probability of tornado outbreak increases from 9% to 20% south of the Ohio River (KY, TN, MS, AL and GA) in April**
- **La Niña decay phase: probability of tornado outbreak increases from 12% to 24% over the central U.S. (IL and IN) in April**

Summary

- **AOML quickly responded to the needs for research to understand the cause of 2011 U.S. tornado outbreak and to identify the source of potential long-range predictability of major U.S. tornado outbreaks**

  1. **(+) Trans-Niño that typically appears during La Niña decay phase is associated about 70% of major U.S. tornado outbreaks since 1951**

  2. **Probability of regional U.S. tornado outbreaks under various types of springtime ENSO phase evolution is identified**

Future work

- **We will continue to explore and build theoretical and observational basis for springtime ENSO phase evolution and its teleconnection to the U.S.**

- **We will move forward with our goals to explore and build a seasonal tornado outlook**

Other researches on extreme weather

- **Impacts of the Ocean on TCs and U.S. Drought**: The Atlantic warm pool plays an important role in TC activity (Goni et al. 2009, 2013; Wang and Lee 2009; 2010; Wang et al. 2011) and U.S. drought (Liu et al. 2012; 2013).
- **Dust, Hurricanes and Climate**: Dust concentration in the TNA inversely varies with Atlantic hurricanes on multidecadal timescale, and suggests a positive feedback role in the AMO via Sahel rainfall (Wang et al. 2012).
- **Global Warming and Hurricanes**: Differential inter-ocean basin warming is associated with an increase of vertical wind shear in the MDR, which reduces hurricane activity (Lee et al. 2011; Wang and Lee 2008).
- **El Niño and Hurricanes:** Non-canonical El Niño pattern, known as El Niño Modoki, has insubstantial impact on Atlantic TC activity (Larson et al. 2012; Lee et al. 2010).

Thank you very much

Questions?

References

- Larson, S., S.-K. Lee, C. Wang, E.-S. Chung, and D. Enfield, 2012: Impacts of non-canonical El Nino patterns on Atlantic hurricane activity. *Geophys. Res. Lett.*, 39, L14706, doi:10.1029/2012GL052595.
- Lee, S.-K., D. B. Enfield and C. Wang, 2011: Future impact of differential inter-basin ocean warming on Atlantic hurricanes. *J. Climate*, 24, 1264-1275.
- Lee, S.-K., R. Atlas, D. B. Enfield, C. Wang and H. Liu, 2013: Is there an optimal ENSO pattern that enhances large-scale atmospheric processes conducive to major tornado outbreaks in the U.S.? *J. Climate*, 26, 1626-1642.
- Lee, S.-K., B. E. Mapes, C. Wang, D. B. Enfield and S. J. Weaver, 2014: Springtime ENSO phase evolution and its relation to rainfall in the continental U.S. *Geophys. Res. Lett.*, doi:10.1029/2013GL059137., In-press
- Liu, H., C. Wang, S.-K. Lee and D. B. Enfield, 2012: Atlantic warm pool variability in the IPCC twentieth-century climate simulations. *J. Climate*, 25, 5612-5628, doi:10.1175/JCLI-D-11-00376.1.
- Liu, H., C. Wang, S.-K. Lee and D. B. Enfield, 2013: Atlantic warm pool variability in the CMIP5 simulations. *J. Climate*, 26, 5315-5336.
- Goni, G.J., 2009: Tropical cyclone heat potential. In State of the Climate in 2007, D.H. Levinson and J.H. Lawrimore (eds.). *Bull. Am. Met. Soc.*, 88(7):S43-S45.
- Goni, J. G., J. A. Knaff, and I-I Lin, 2013: Tropical cyclone heat potential. [in "State of the Climate in 2012"]. *Bull. Amer. Meteor. Soc.*, 94 (8) S99-100.
- Wang, C. and S.-K. Lee, 2008: Global warming and United States landfalling hurricanes. Geophys. Res. Lett., 35, L02708, doi:10.1029/2007GL032396.
- Wang C. and S.-K. Lee, 2009: Co-variability of tropical cyclones in the North Atlantic and the eastern North Pacific. Geophys. Res. Lett., 36, L24702, doi:10.1029/2009GL041469.
- Wang, C., H. Liu, S.-K. Lee and R. Atlas, 2011: Impact of the Atlantic warm pool on United States landfalling hurricanes. Geophys. Res. Lett., doi:10.1029/2011GL049265
- Wang, C., S. Dong, A. T. Evan, G. R. Foltz, and S.-K. Lee, 2012: Multidecadal co-variability of North Atlantic sea surface temperature, African dust, Sahel rainfall and Atlantic hurricanes. J. Climate, 25, 5404-5415,