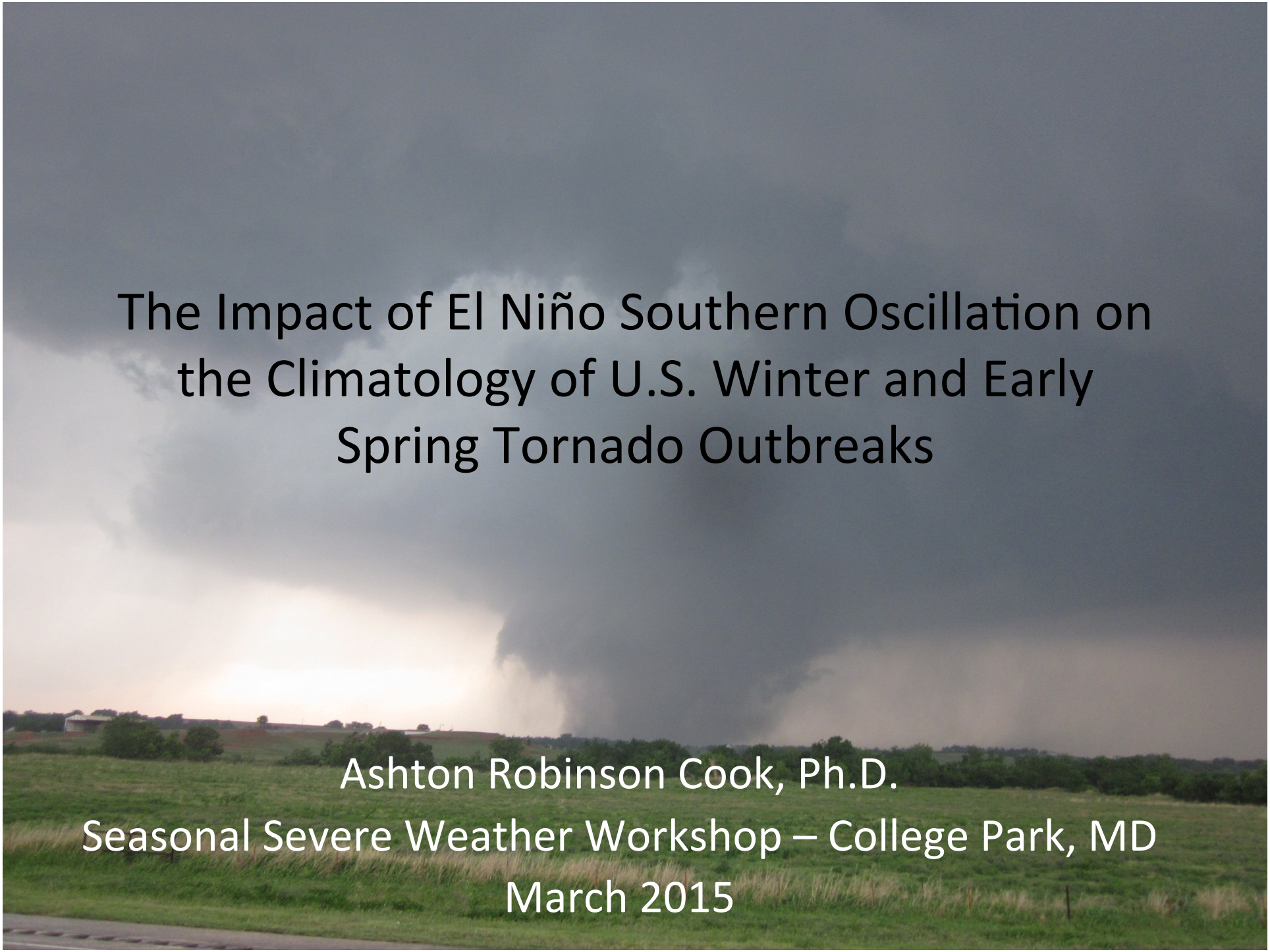


The Impact of El Niño Southern Oscillation on the Climatology of U.S. Winter and Early Spring Tornado Outbreaks

Ashton Robinson Cook, Ph.D.

Seasonal Severe Weather Workshop – College Park, MD

March 2015

Seasonal tornado forecasts?

Official White House Photo by Pete Souza – May 29, 2011

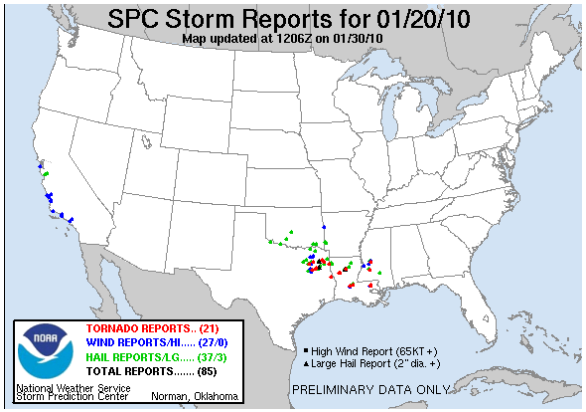
Presidential/high-level interest in a seasonal tornado forecast after the historic tornado outbreaks…

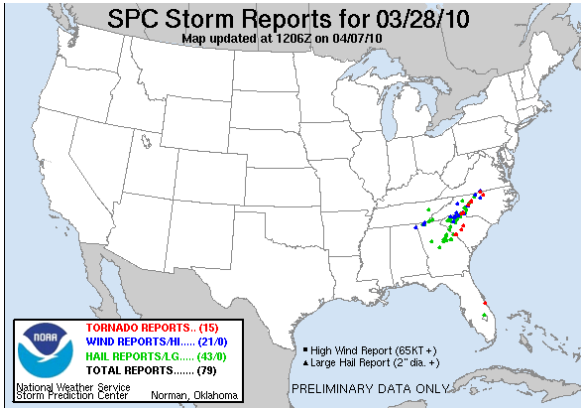
Seasonal tornado forecasting

- SPC experimental winter tornado outlook statement first issued internally in October 2009 for upcoming El Niño winter of 2010

Excerpt from experimental winter tornado outlook:

"Even though tornadoes can occur anywhere and at any time during the year, El Niño events have historically been associated with the development of cold season tornado activity along the southern U.S. near the Gulf Coast from Texas eastward to Florida. Central Florida has experienced the brunt of this activity over the years, with particularly deadly nighttime tornado activity occurring in February 1998 and February 2007. Other recent deadly cold season tornado outbreaks have affected parts of Georgia, Texas, and Mississippi during El Niño conditions." [emphasis added]





Goals and Objectives

- Set the foundation for further development of a seasonal tornado prediction tool in two ways:
  - By gaining a better understanding of winter and early spring (January-April) climatology of tornado outbreaks east of the Rocky Mountains…
  - And diagnosing the influence of El Niño/La Niña on synoptic-scale atmospheric features commonly associated with tornado outbreaks

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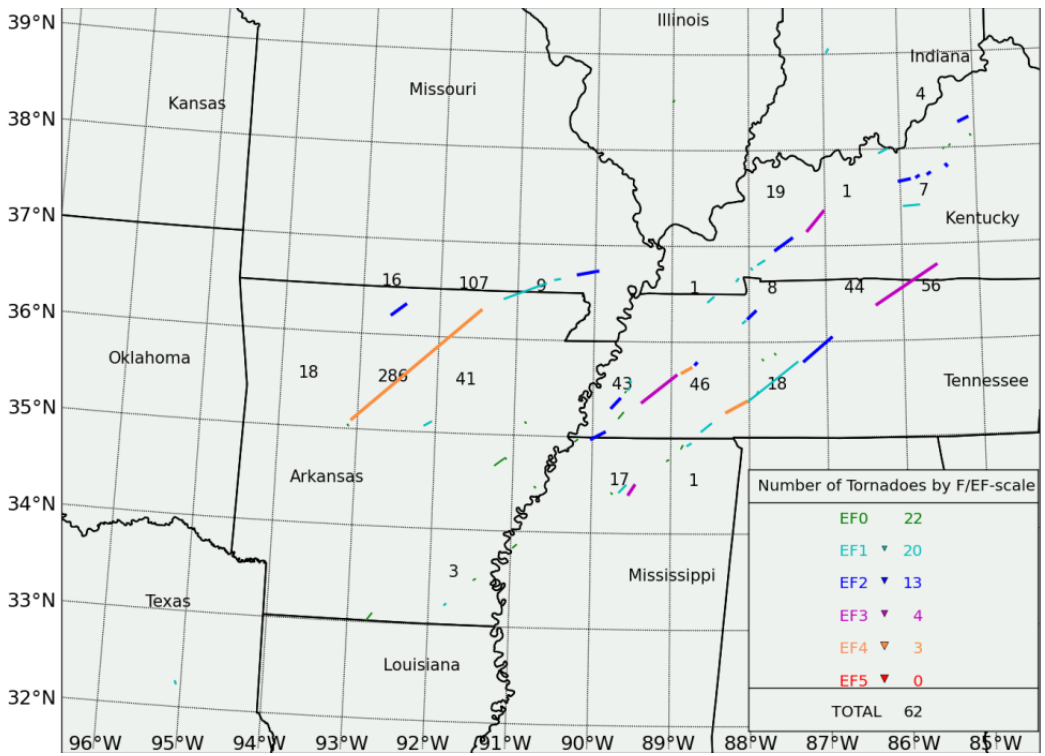
Data and Methodology: Physical Climatology

- Dataset: NOAA/NWS/NCEP SPC Tornado/Severe Thunderstorm database (Schaefer et al. 1980, Schaefer and Edwards 1999)
- Tornado outbreak days defined as days containing 6 or more tornadoes in the CONUS east of the Rocky Mountains
- Gridded Destruction Potential (Thompson and Vescio 1998, Doswell et al. 2006)



$$\mathrm{DPI} = \sum_{i=1}^{n} a_i \left(F_i + 1 \right)$$

Tornado tracks (color coded by EF-scale rating) and 1° gridded DPI from the Super Tuesday Tornado Outbreak of February 5, 2008

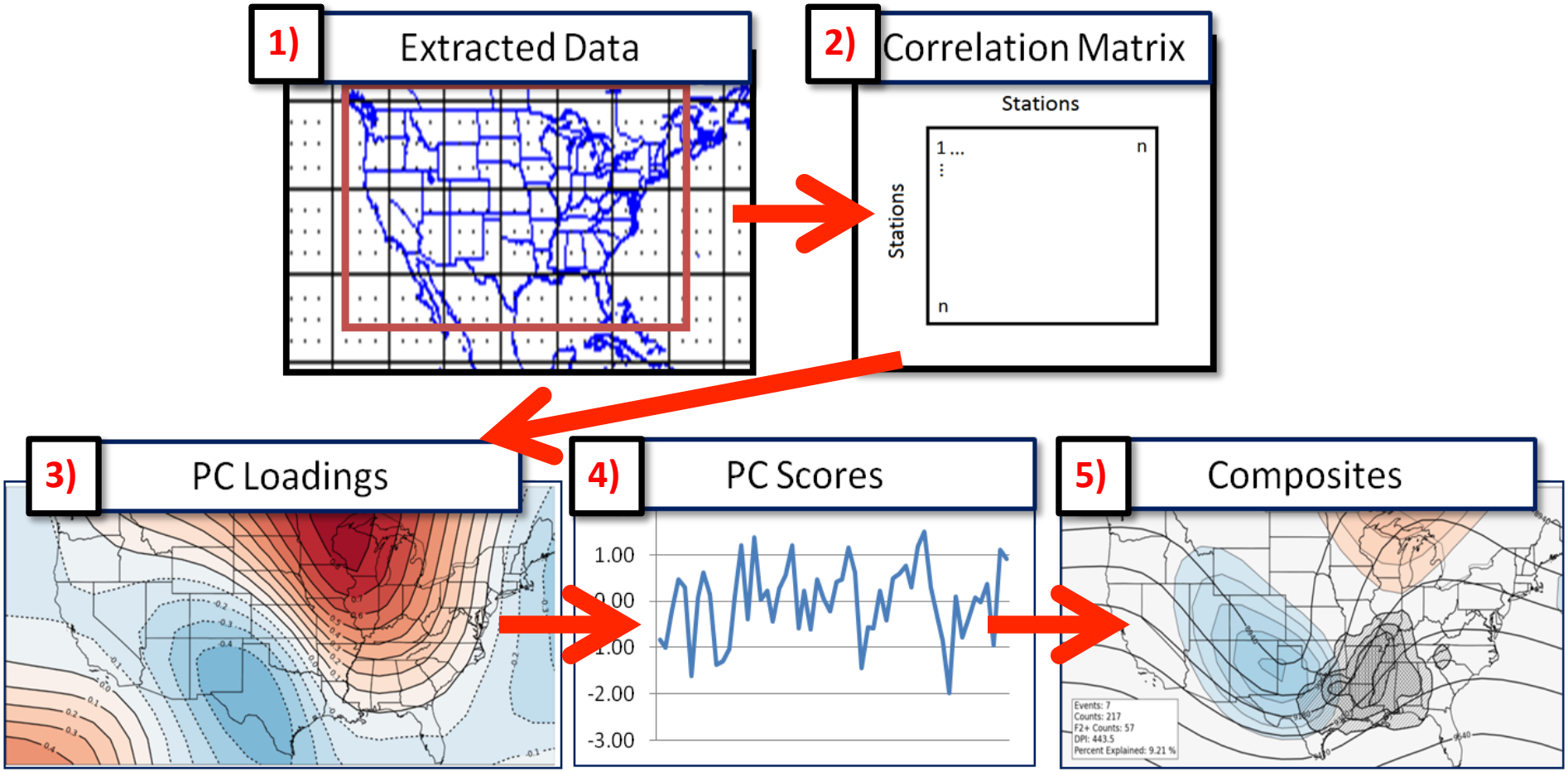
Data and Methodology: Physical Climatology

- Statistical tests
  - **B**ias-**C**orrected, **a**ccelerated **C**onfidence **I**ntervals (BCa CI; Efron and Tibshirani 1993, Dixon et al. 2011)
    - Classes of data compared to determine whether changes in tornado activity are statistically significant using BCa CIs
    - Technique was used by Dixon et al. 2011 to investigate whether a separate tornado alley exists in the Southern U.S. apart from the Great Plains

Data and Methodology: Atmospheric Climatology

- Primarily involves use of Principal Component Analysis to generate composites of groups of outbreaks with similar spatial anomalies
- Purpose
  - Help identify shifts in synoptic-scale atmospheric features associated with groups of *individual* tornado outbreaks that are influenced by larger-scale climate components
  - Approach provides deeper insight into variability within subsets of tornado outbreaks than monthly or seasonal averages (Mercer 2008)

Data and Methodology: Atmospheric Climatology



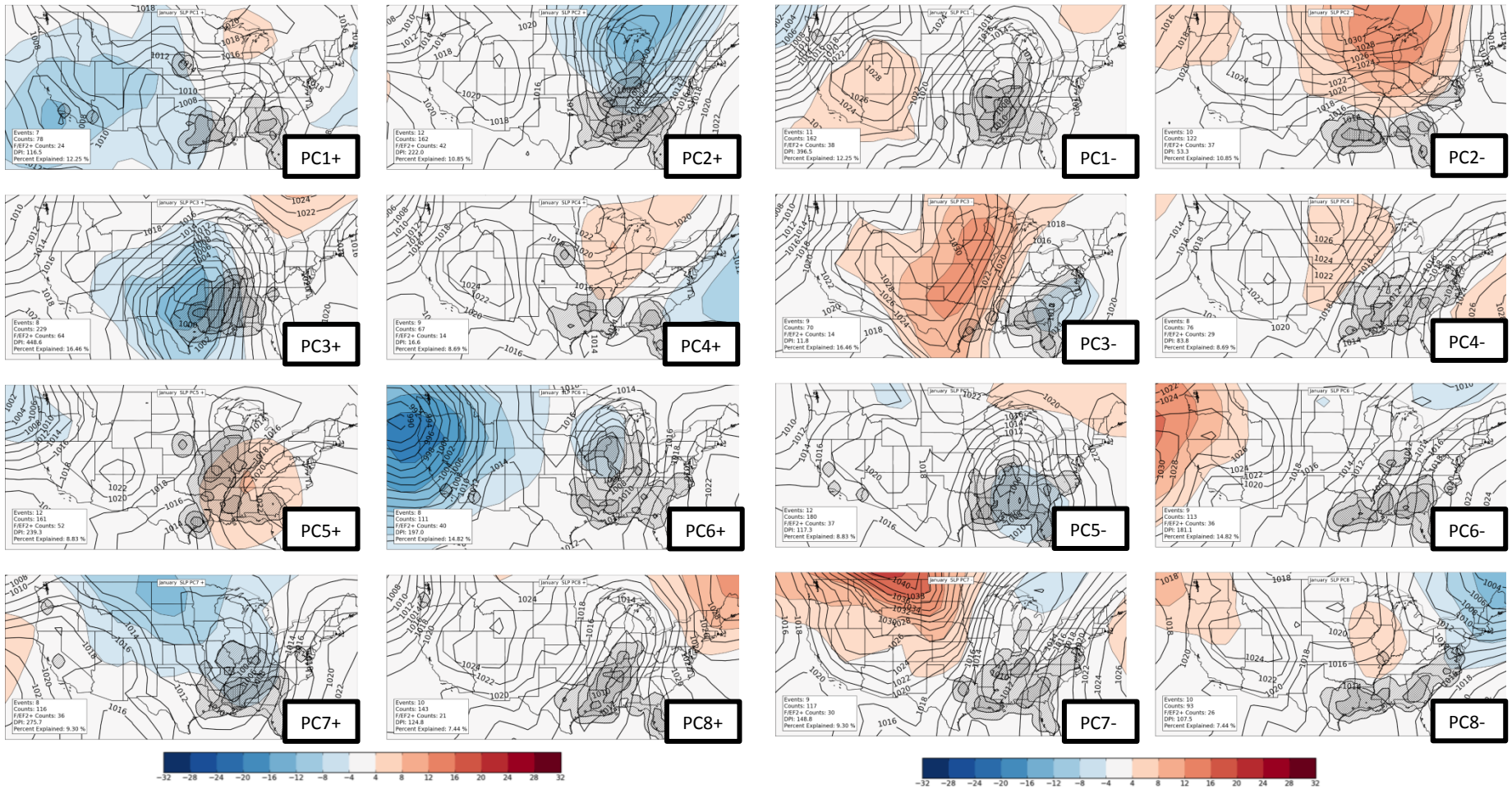
Data and Methodology: Atmospheric Climatology

Synoptic-scale Atmospheric Features of Interest	Atmospheric Variable Used to Identify Features	Contribution toward Tornado Outbreaks	Reference
Upper-tropospheric Jet Stream	300 hPa ϕ, U Wind, V Wind	Lifting Mechanism, Shear	RC 1982, RH 1987
Surface Cyclones	Sea Level Pressure, U Wind, V Wind	Lifting Mechanism, Shear	EH 2006
Lower-tropospheric Jet Stream (LLJ)	850 hPa ϕ, U Wind, V Wind	Lifting Mechanism, Shear	S 1998
Static Instability	Lifted Index	Instability	SS 2006
Moisture	Precipitable Water	Moisture	S 1998, SS 2006

- Data extraction was focused on five different variables that were used to identify synoptic-scale atmospheric features
- Extracted data was specifically chosen to identify synoptic-scale features contributing to tornado outbreaks that are also known to be influenced by larger-scale climate oscillations (ENSO)
- For the creation of the atmospheric climatology, extracted data was further binned by month and single variable (i.e., January 300 hPa geopotential).
- Comparisons of composites across months are used to develop the atmospheric climatology
- Variables in red: Composites of wind fields were generated using results of PCA of corresponding geopotential height or sea level pressure

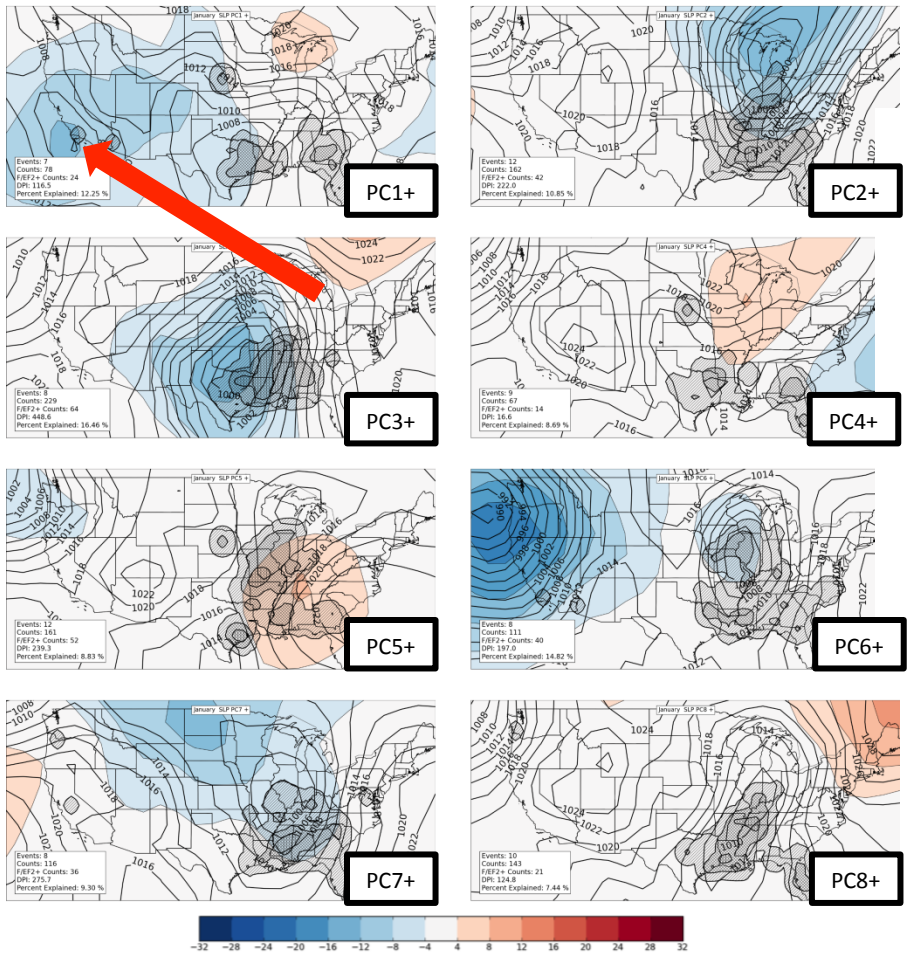
Data and Methodology: Atmospheric Climatology

- Example result of PCA: Composites of SLP for all January outbreaks
- Shadings indicate anomalies; hatched areas indicate tornadoes

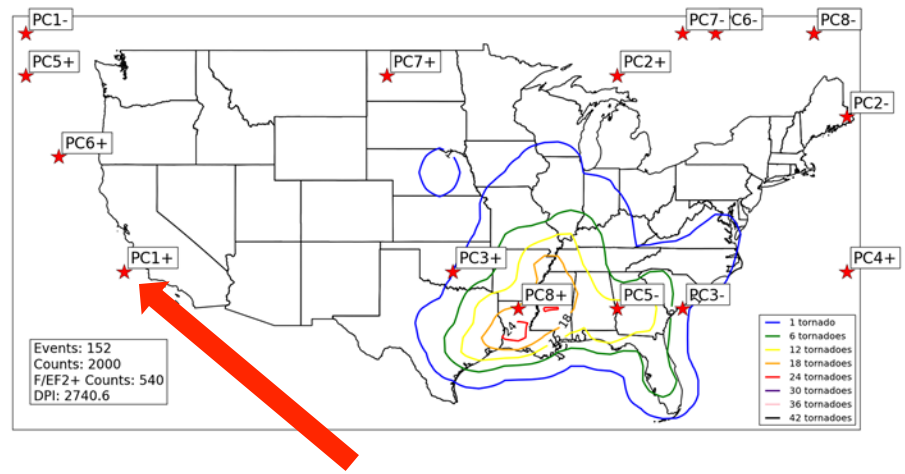


Data and Methodology: Atmospheric Climatology

- Information condensed into one plot



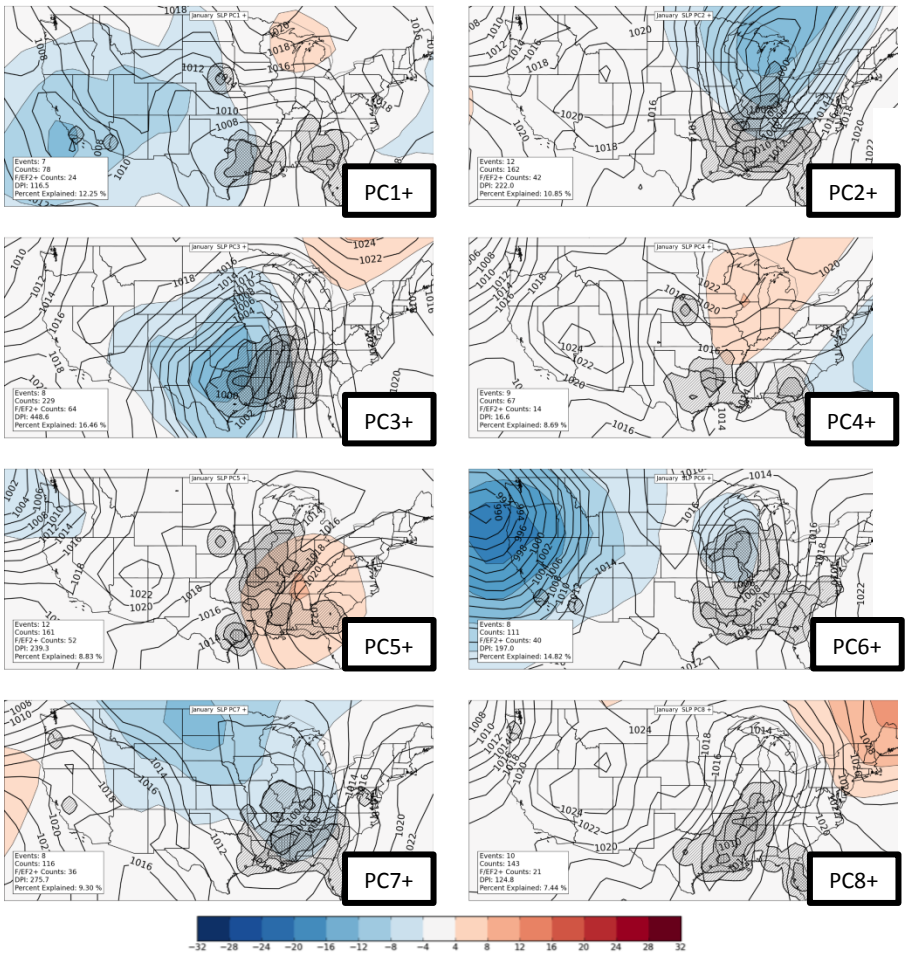
January SLP



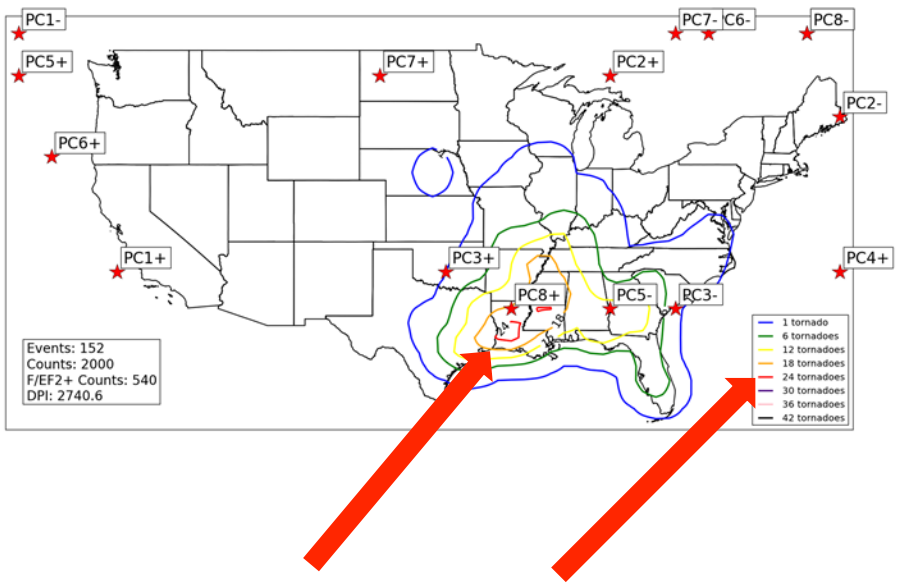
Location of largest negative departure of composite SLP mean from monthly SLP mean in all outbreak (indicated by red star)

Data and Methodology: Atmospheric Climatology

- Information condensed into one plot



January SLP



Contours represent tornado activity from individual outbreaks included in each composite (Tallied and plotted similarly to earlier gridded 1 by 1 grid methodology)

Results: ENSO Physical Climatology

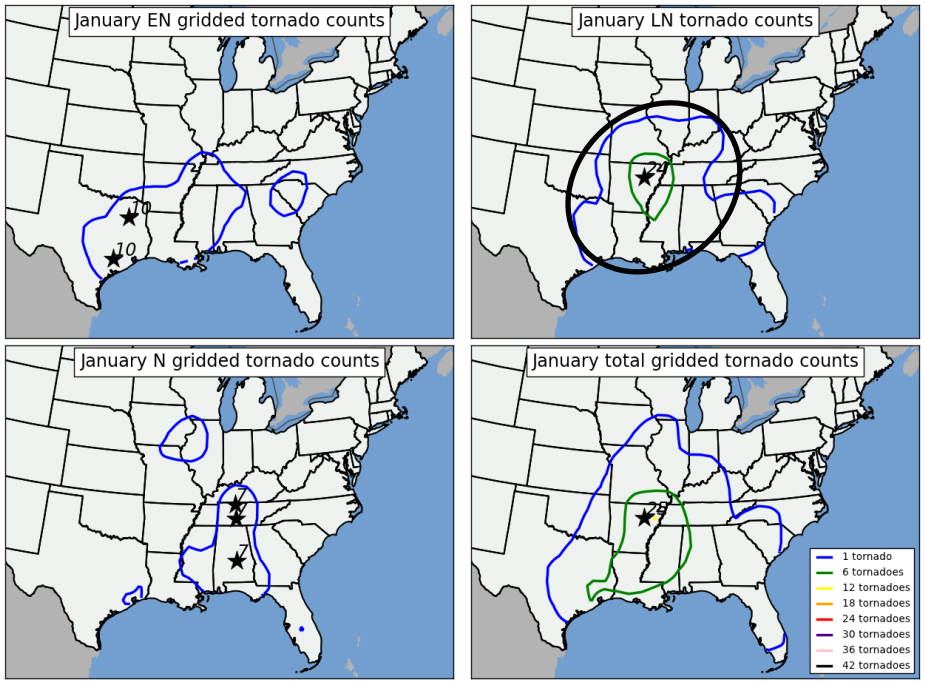
- LN conditions consistently foster increased tornado activity (including tornado counts and tornado outbreak counts)

	January			February			March			April		
	EN	LN	N	EN	LN	N	EN	LN	N	EN	LN	N
Tornadoes on outbreak days	221	412	160	151	418	323	205	788	1492	842	1614	3120
Tornadoes per Number of Months in each ENSO phase	10.52	19.62	8.42	11.62	23.22	10.77	20.50	46.35	43.88	69.67	100.88	94.18
Tornado outbreak days	23	21	12	17	36	30	20	68	100	63	113	214
Outbreak days per Number of Months in each ENSO phase	1.10	1.00	0.63	1.31	2.00	1.00	2.00	4.00	2.94	5.25	7.06	6.48
Tornadoes rated F/EF2 or greater	48	107	74	43	148	114	38	213	556	223	611	818
F/EF2+ tornadoes per number of months in each ENSO phase	2.29	5.10	3.89	3.31	8.22	3.80	3.80	12.53	16.35	18.58	38.19	24.79
Tornadoes rated F/EF4 or greater	2	3	5	1	12	4	1	12	47	19	70	63
F/EF4+ tornadoes per number of months in each ENSO phase	0.10	0.14	0.26	0.08	0.67	0.13	0.10	0.71	1.38	1.58	4.38	1.91
Number of months in each ENSO phase	21	21	19	13	18	30	10	17	34	12	16	33

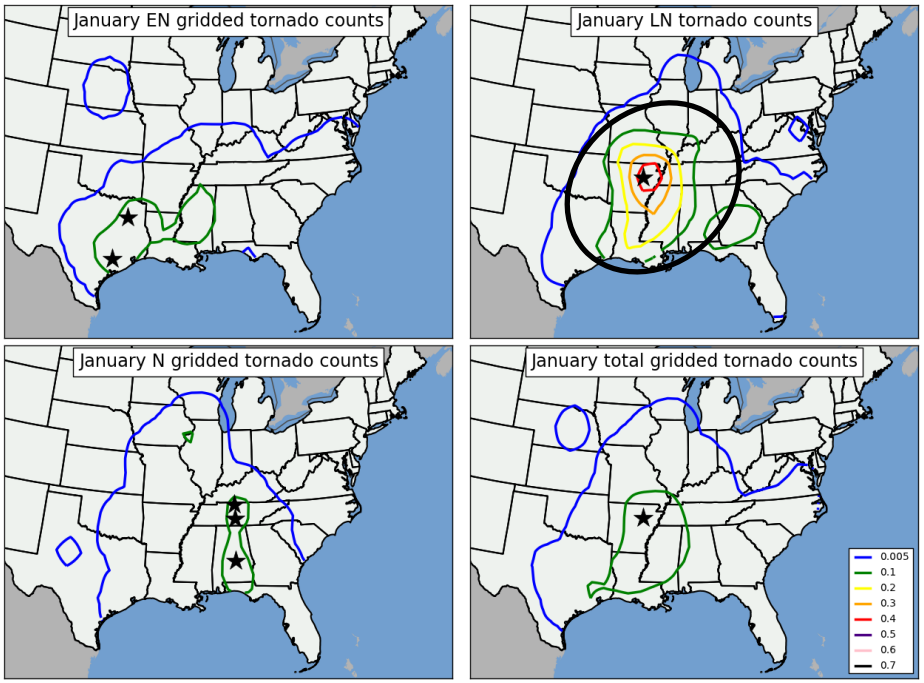
January-April 1950-2010 tornado frequency in outbreaks east of the Rocky Mountains. Outbreaks are binned and then tallied according to concurrent ENSO phase.

Results: ENSO Physical Climatology

- Tornado activity is also more frequent at farther north latitudes during LN conditions and displaced to the south in EN conditions



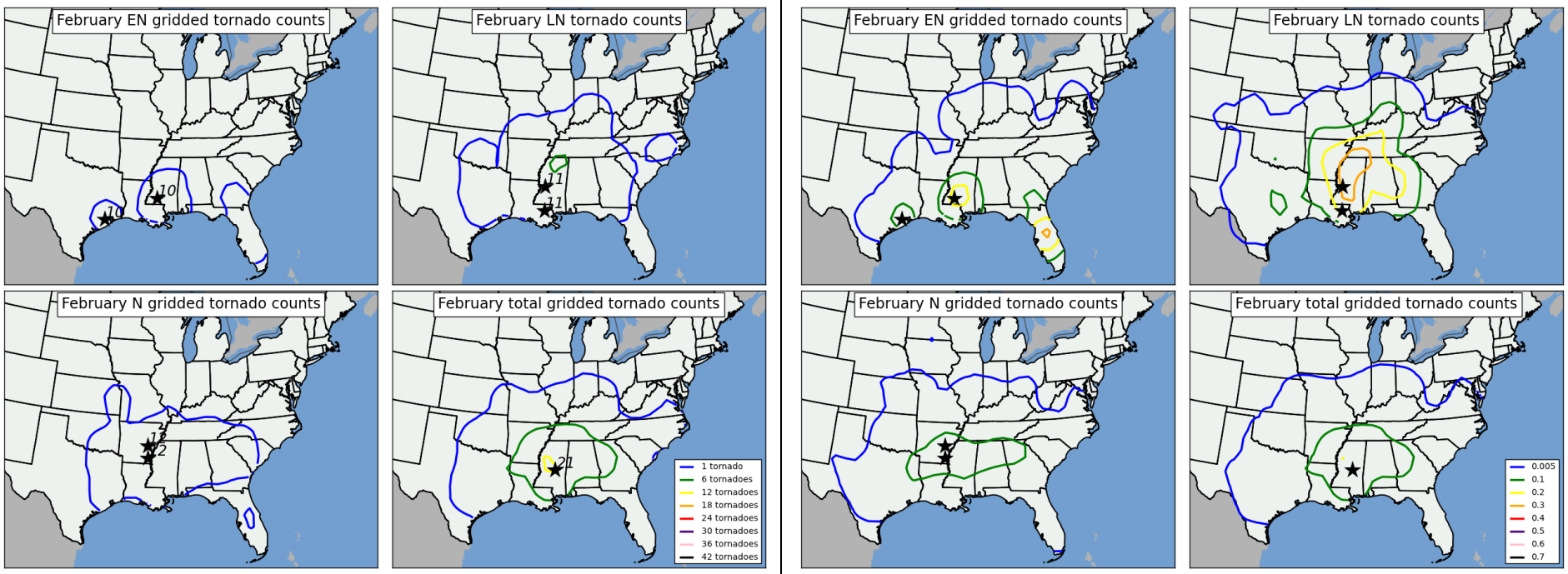
Tornado counts



Tornado counts normalized by number of times a particular ENSO phase occurred in the 61 year period

Results: ENSO Physical Climatology

- February gridded tornado activity (1° by 1° grid) stratified into EN/LN/N phase of ENSO

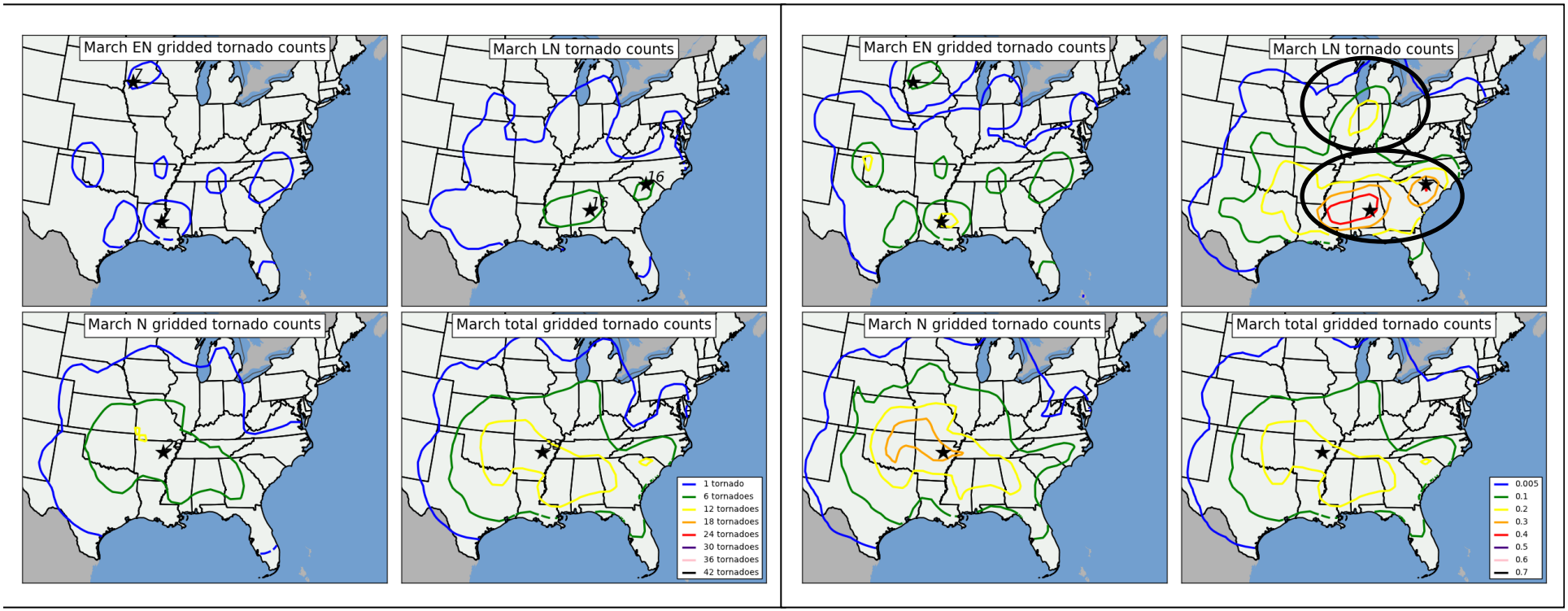


Tornado counts

Tornado counts normalized by number of times a particular ENSO phase occurred in the 61 year period

Results: ENSO Physical Climatology

- March gridded tornado activity (1° by 1° grid) stratified into EN/LN/N phase of ENSO

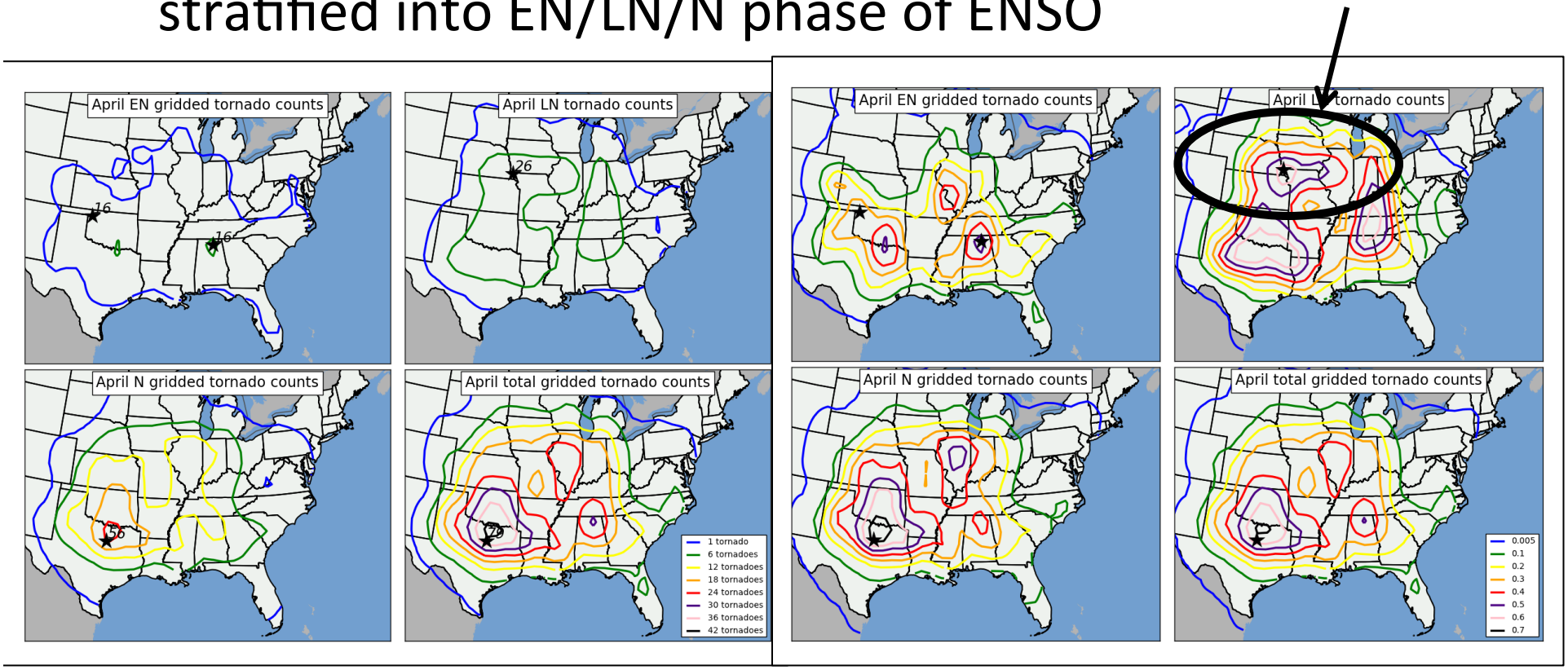


Tornado counts

Tornado counts normalized by number of times a particular ENSO phase occurred in the 61 year period

Results: ENSO Physical Climatology

- April gridded tornado activity (1° by 1° grid) stratified into EN/LN/N phase of ENSO

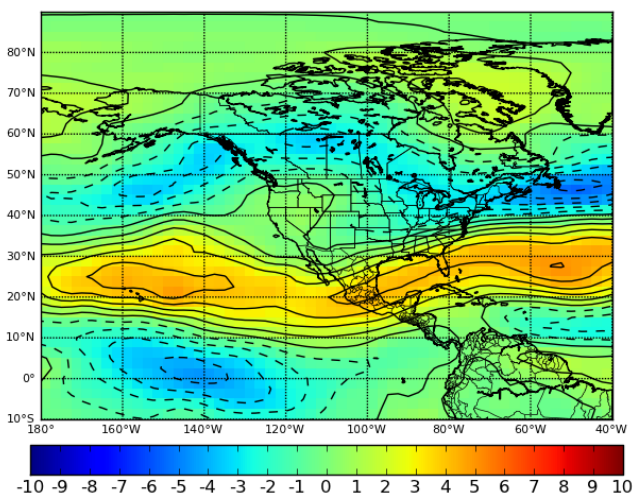


Tornado counts

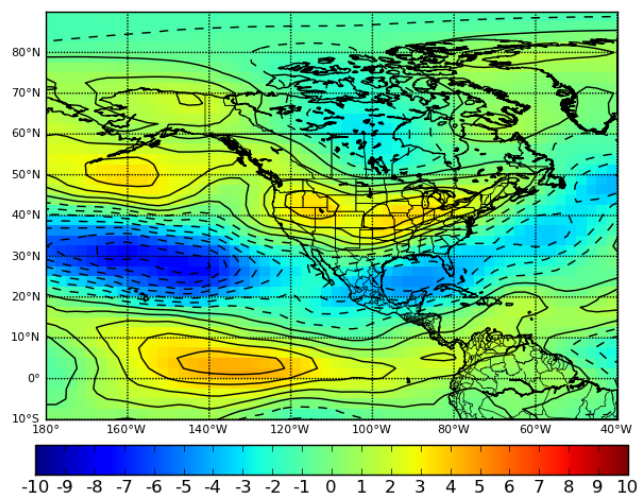
Tornado counts normalized by number of times a particular ENSO phase occurred in the 61 year period

Results: ENSO Atmospheric Climatology

- Southward displacement of tornado activity is explained in part by the southward displacement in the mid- and upper-level jet (present in all months of the study period)
- This displacement is directly tied to ENSO (Rasmusson and Carpenter 1982)



January EN monthly anomalies of 300 hPa scalar wind

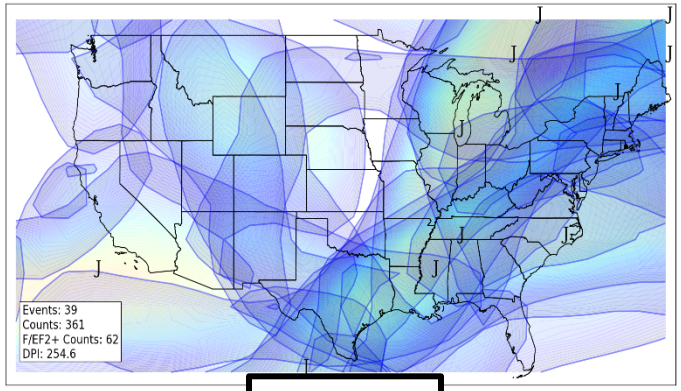


January LN monthly anomalies of 300 hPa scalar wind

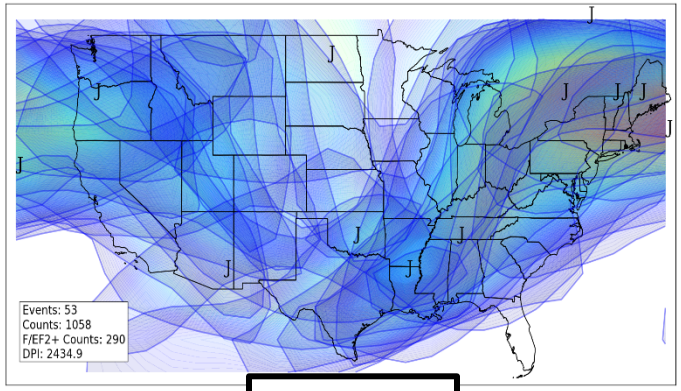
Results: ENSO Atmospheric Climatology

- This displacement is also observed *within outbreaks* especially in February, March, and April

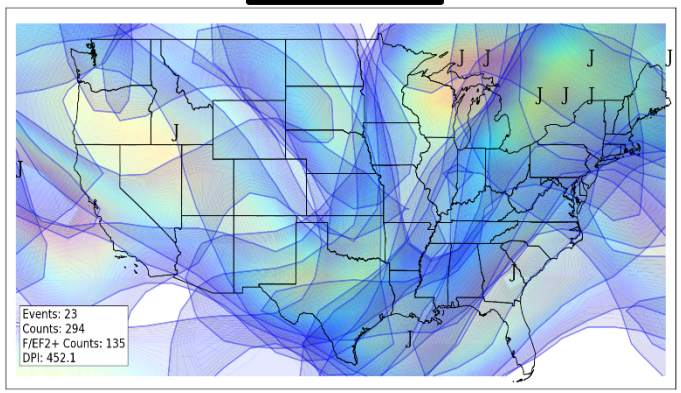
EN January



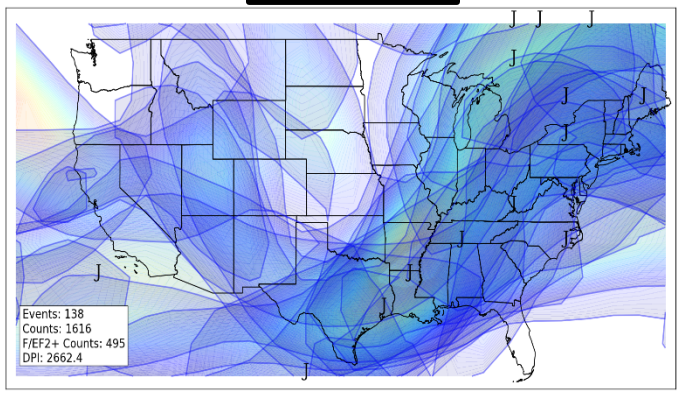
LN January



N January



All January

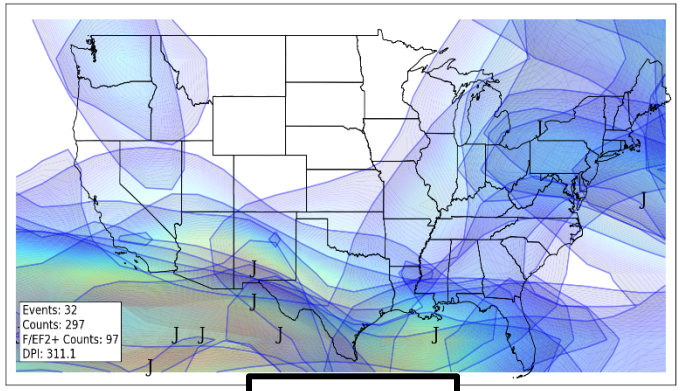


Shaded areas represent 300 hpa jet streams in each composite of 300 hPa geopotential. (Brighter colors indicate stronger winds)

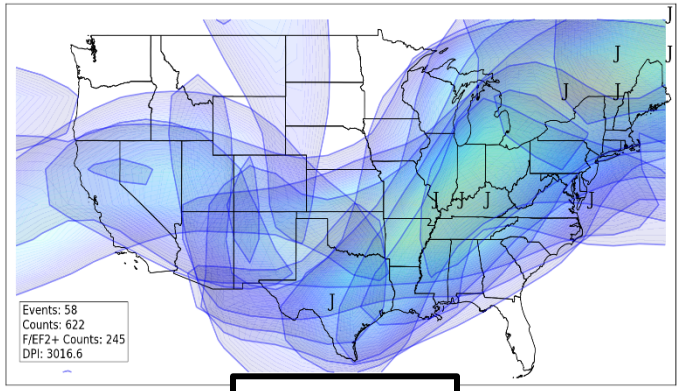
Results: ENSO Atmospheric Climatology

- This displacement is also observed *within outbreaks* especially in February, March, and April

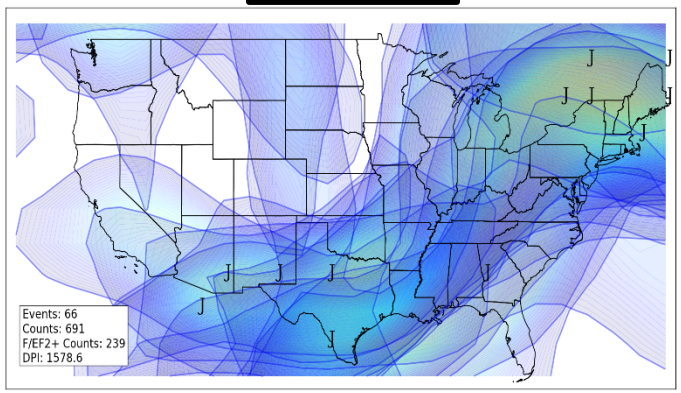
EN February



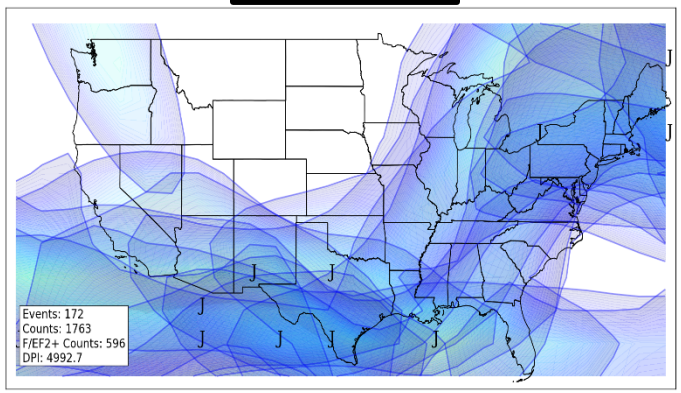
LN February



N February



All February



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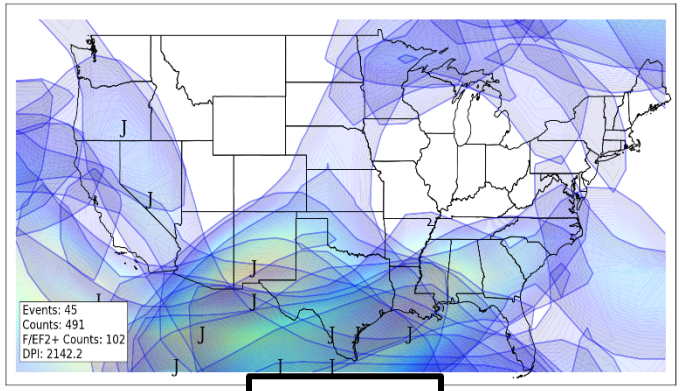
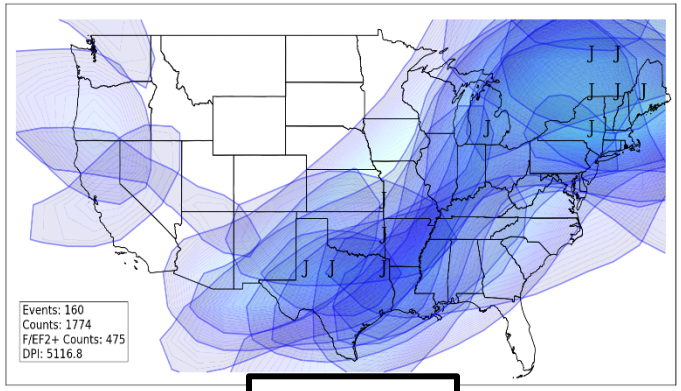
Results: ENSO Atmospheric Climatology

- This displacement is also observed *within outbreaks* especially in February, March, and April

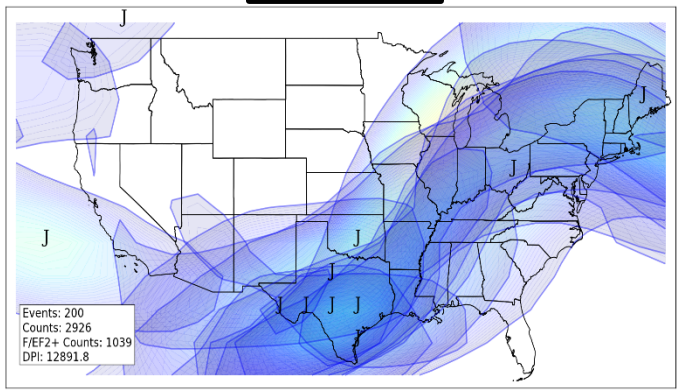
EN March



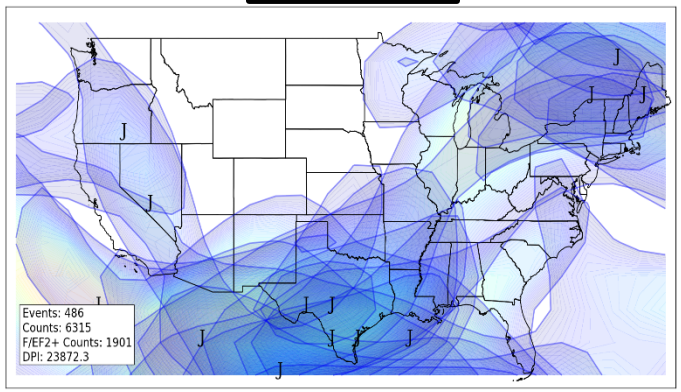
LN March



N March



All March



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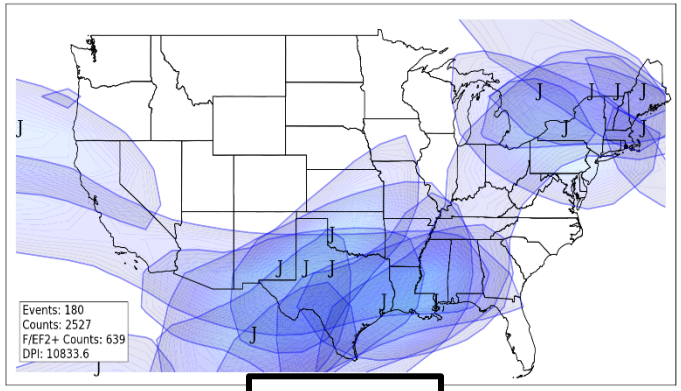
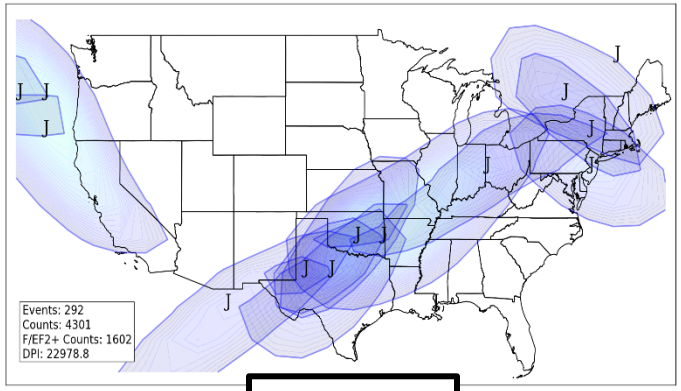
Results: ENSO Atmospheric Climatology

- This displacement is also observed *within outbreaks* especially in February, March, and April

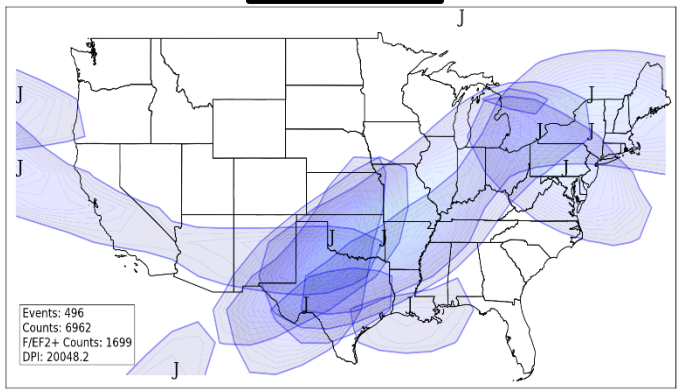
EN April



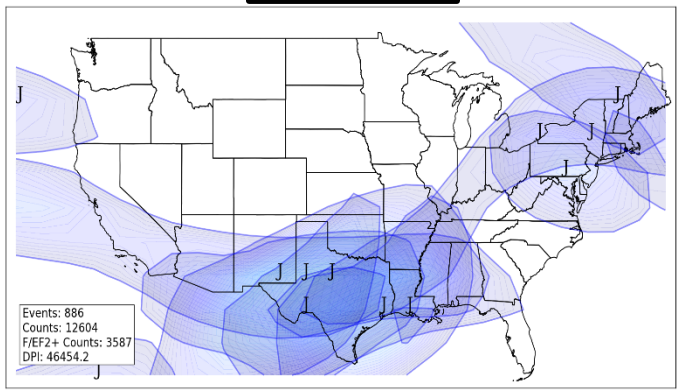
LN April



N April



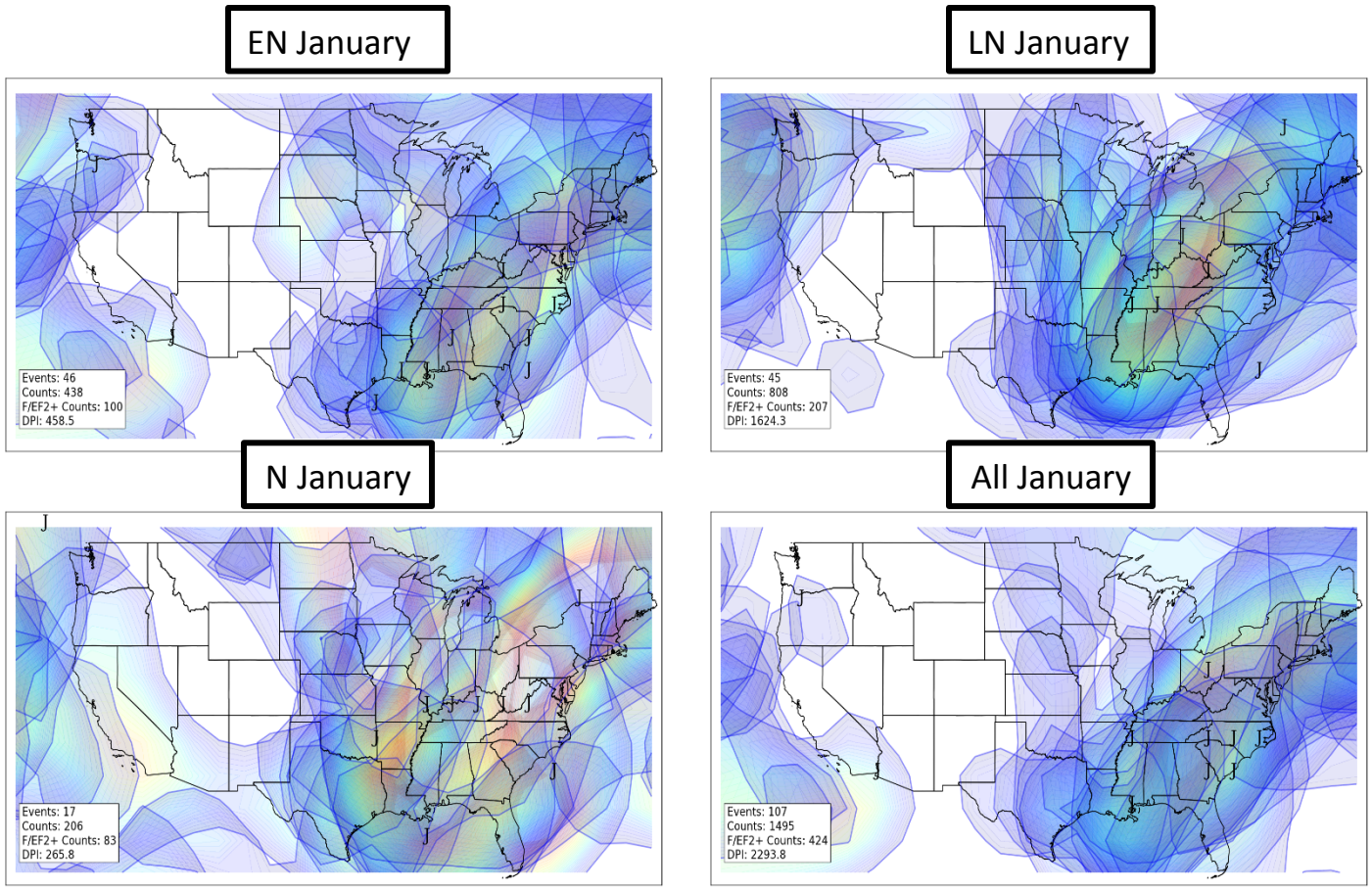
All April



Shaded areas represent 300 hpa jet streams in each composite of 300 hPa geopotential. (Brighter colors indicate stronger winds)

Results: ENSO Atmospheric Climatology

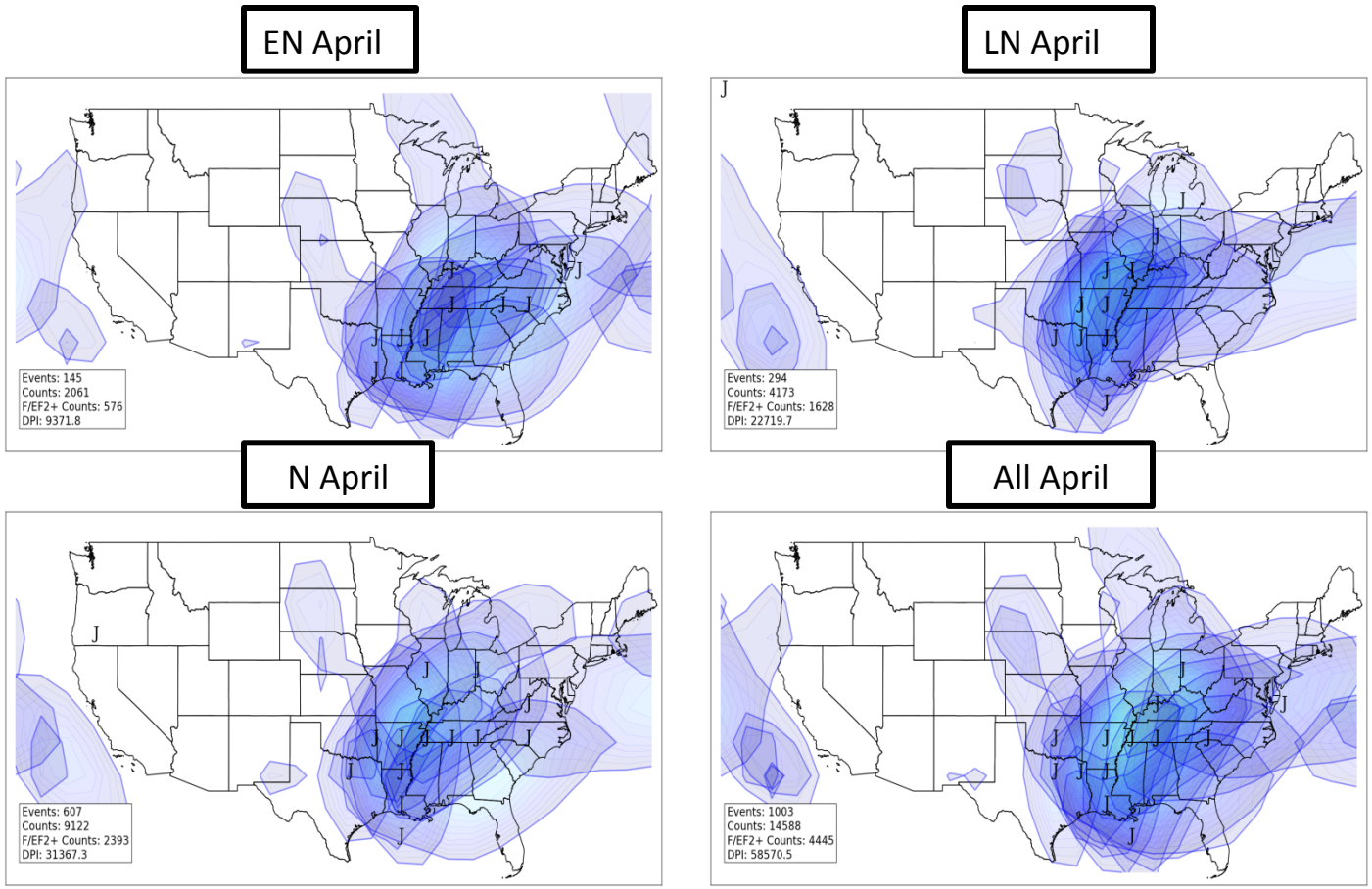
- Synoptic-scale low-level jets are linked to mid- and upper-level jets (Uccellini and Johnson 1979), explaining the southward shift in low-level jet observed during EN conditions



Shaded areas represent 850 hpa jet streams in each composite of 850 hPa geopotential. (Brighter colors indicate stronger winds)

Results: ENSO Atmospheric Climatology

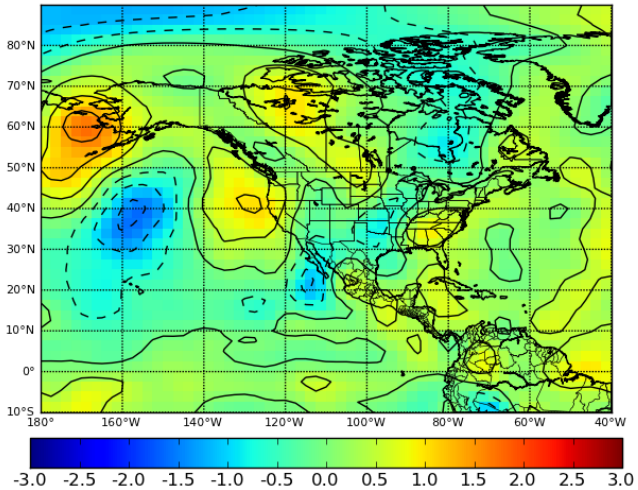
- Synoptic-scale low-level jets are linked to mid- and upper-level jets (Uccellini and Johnson 1981), explaining the southward shift in low-level jet observed during EN conditions



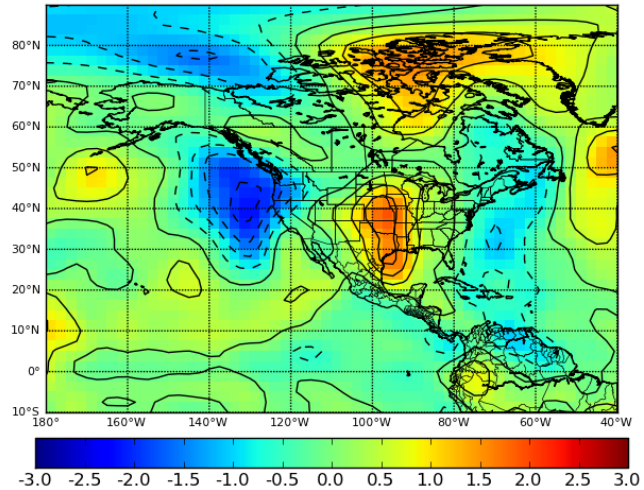
Shaded areas represent 850 hpa jet streams in each composite of 850 hPa geopotential. (Brighter colors indicate stronger winds)

Results: ENSO Atmospheric Climatology

- Evidence of the northward shift in the low-level jet during LN is also apparent independent of outbreaks in all months of the study period



April EN monthly anomalies of 850 hPa V-component wind

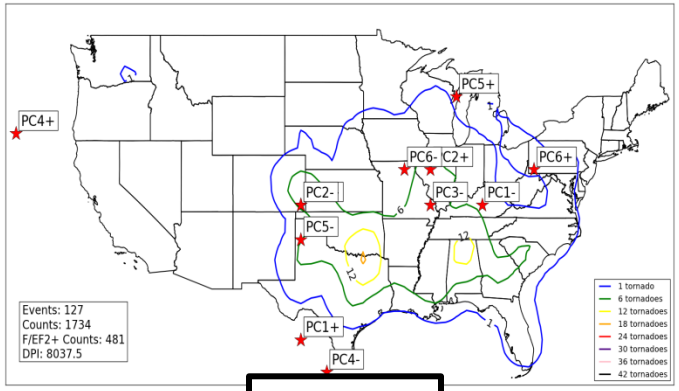


April LN monthly anomalies of 850 hPa V-component wind

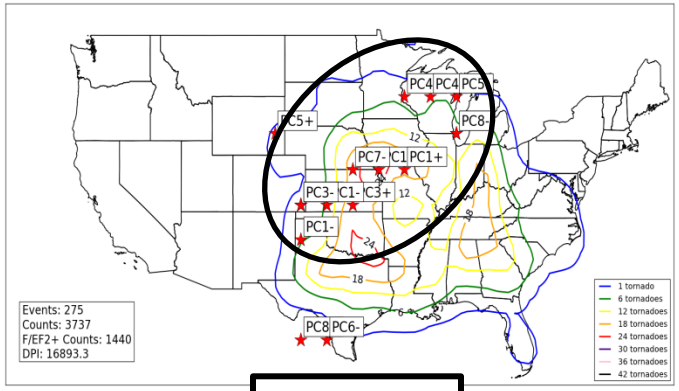
Results: ENSO Atmospheric Climatology

- ENSO-related shifts in surface cyclone activity (identified by location of minimum SLP in domain) are less clear and not consistent from month to month based on outbreak composites.

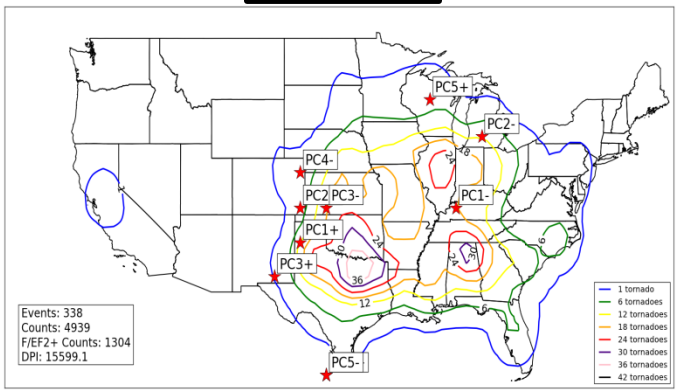
EN April



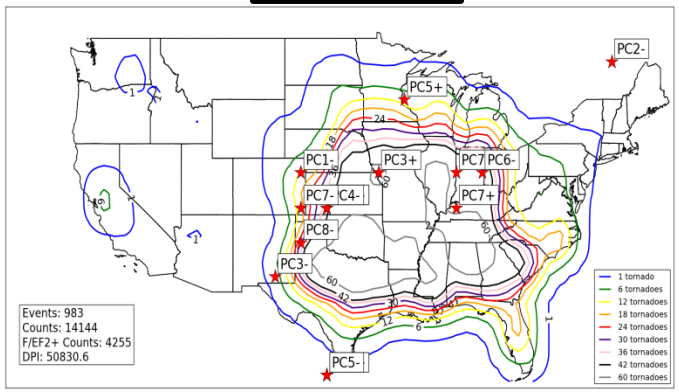
LN April



N April



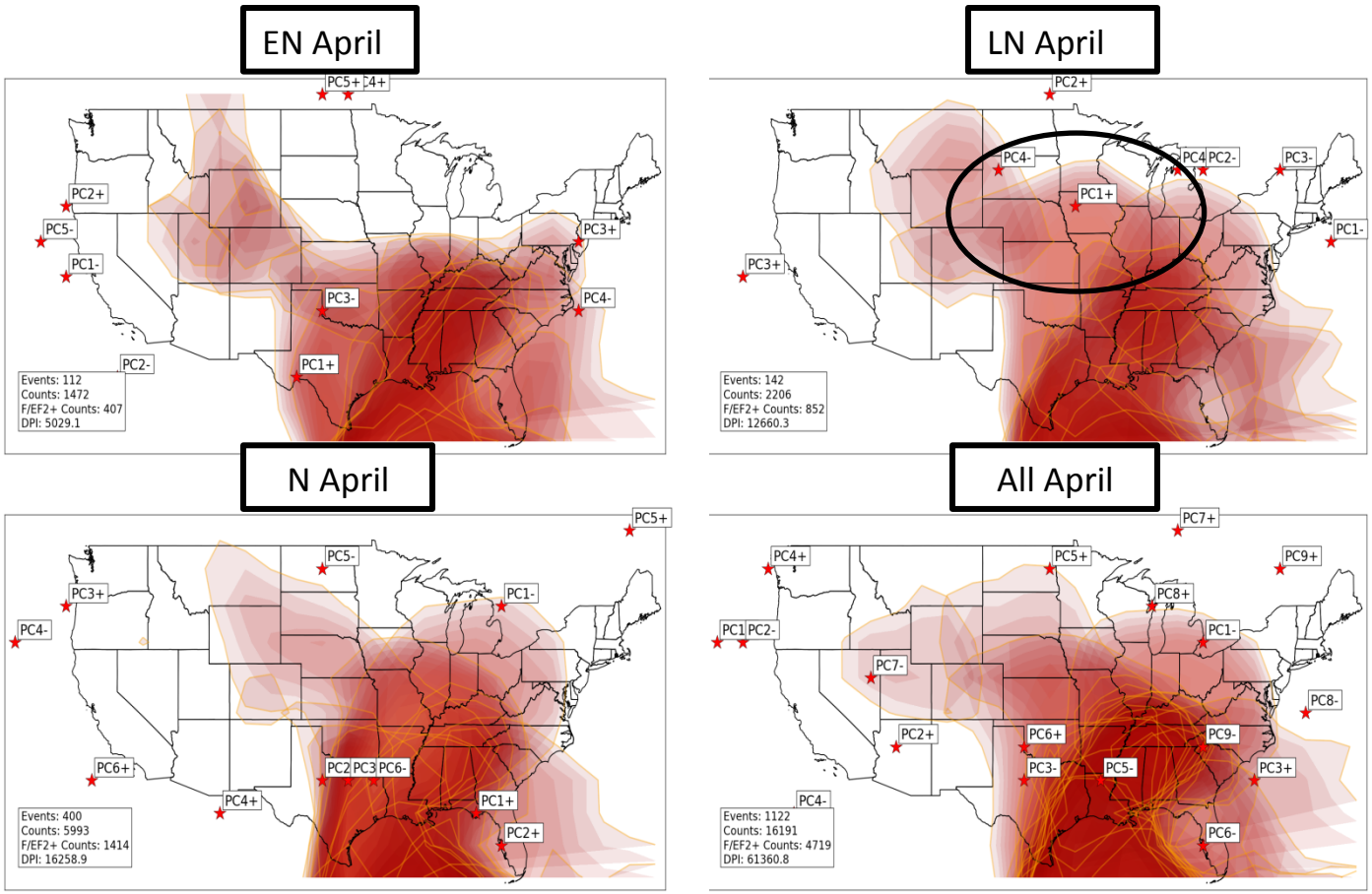
All April



Stars represent SLP minima in each composite

Results: ENSO Physical Climatology

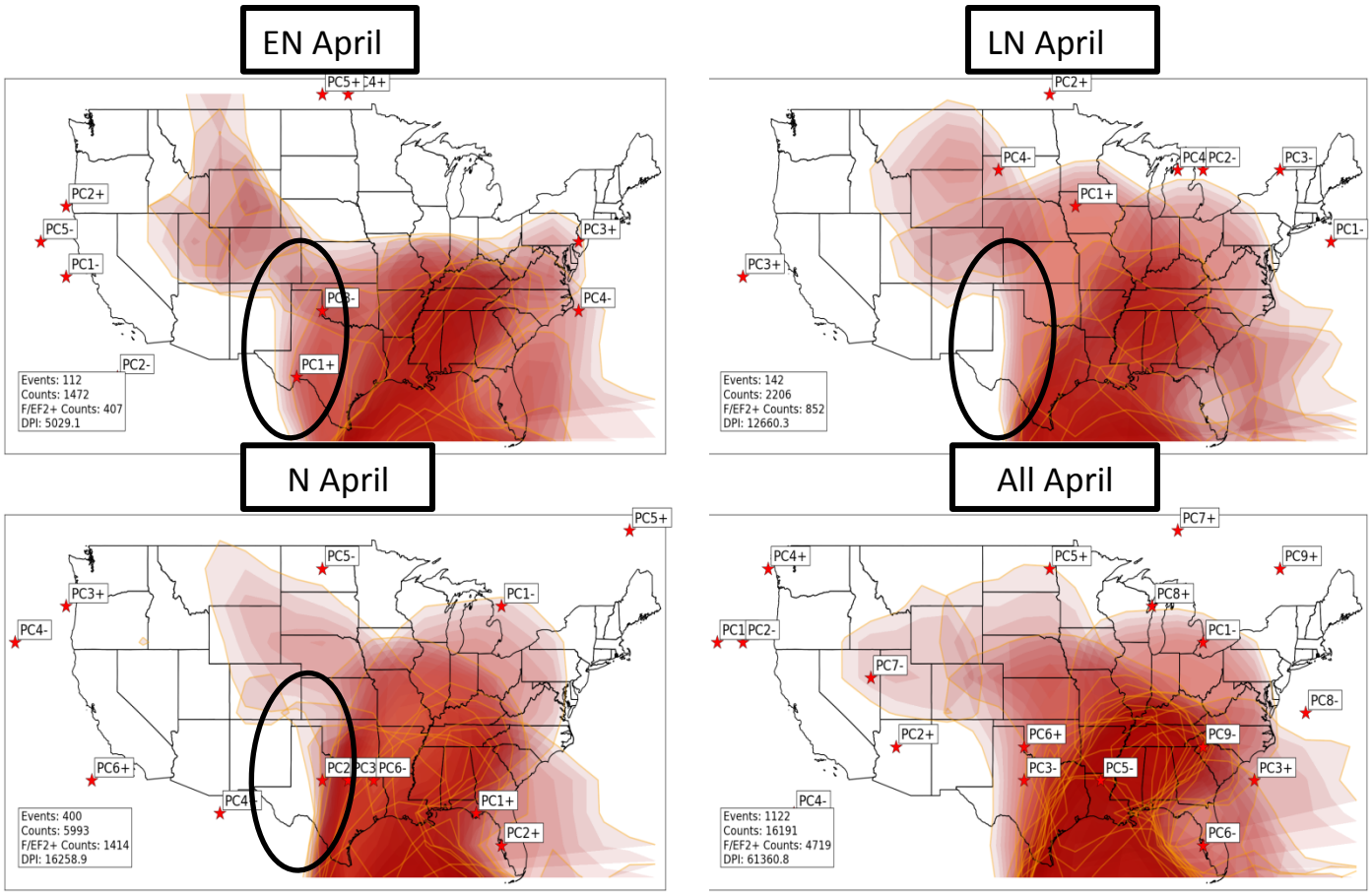
- Shifts in static instability (lifted index)



Stars represent maximum LI anomaly in each composite

Results: ENSO Physical Climatology

- Shifts in static instability (lifted index)



Stars represent maximum LI anomaly in each composite

Key Conclusions

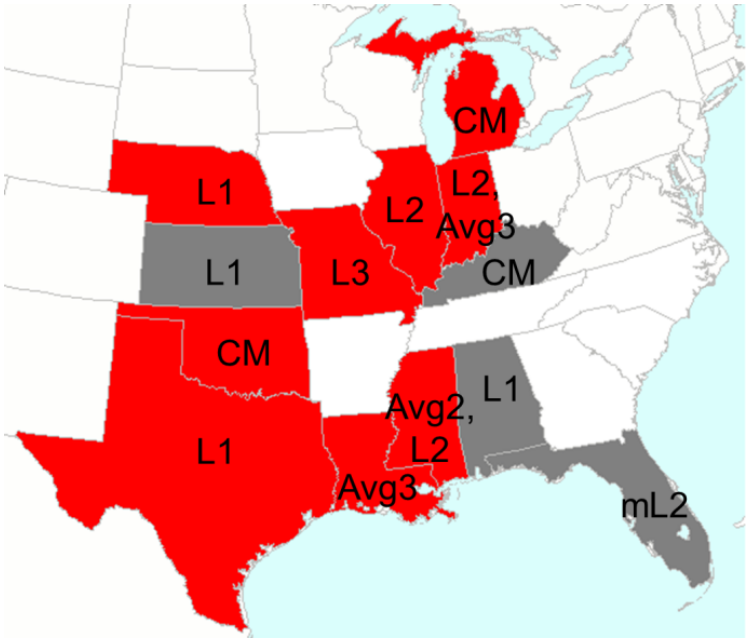
- Southward/northward displacement in tornado activity during EN/LN phase tornado outbreaks
- ENSO/atmospheric climatology also appears to corroborate these shifts
  - Most apparent in 850 hPa V-component wind and 300 hPa scalar wind fields (outbreak composites and monthly anomalies)
- Shifts in static instability (i.e., Lifted Index) are generally consistent with shifts in tornado activity and other atmospheric variables
  - Particularly in January and also in April

Questions?

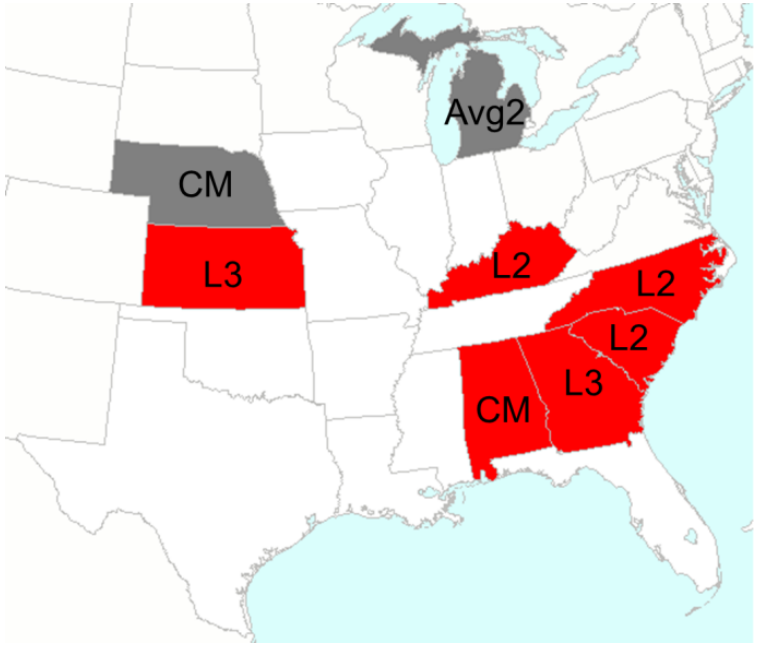
Future work (Post Graduation)

- Continue to expand diagnostic work on the role of additional large-scale climate drivers and tornado outbreaks

PNA



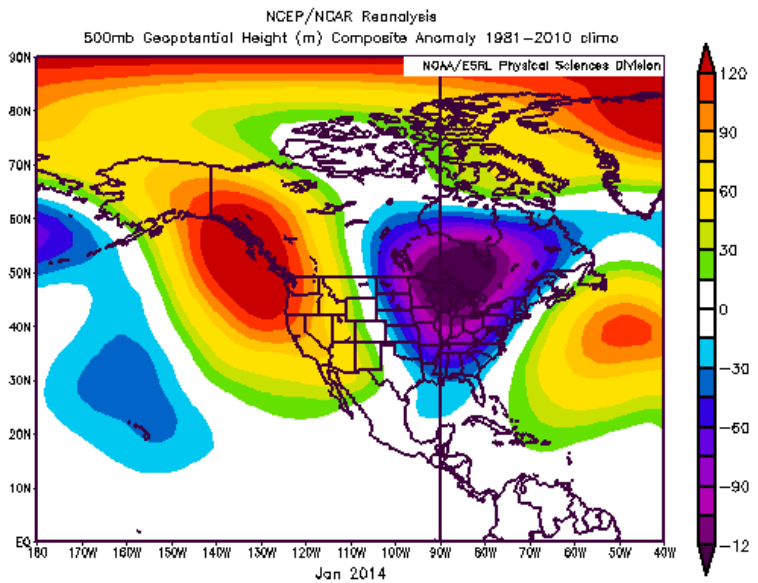
NAO

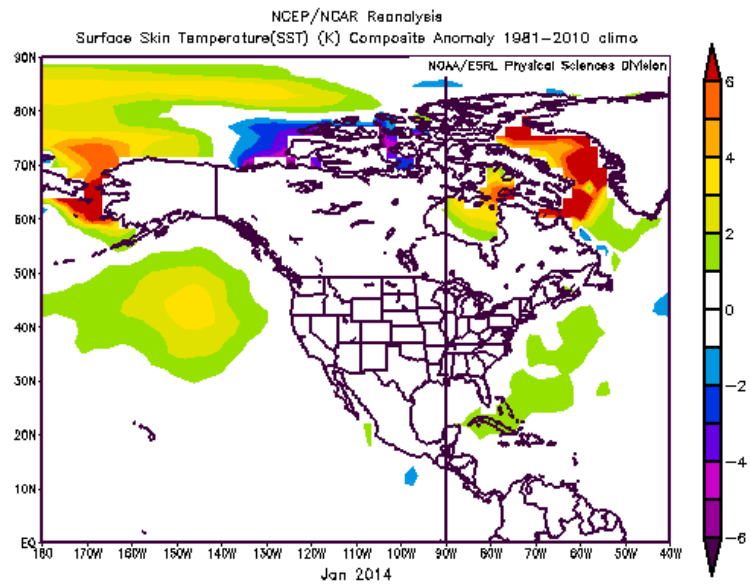


Primary and secondary monthly indices that exhibit greatest influence on state-by-state tornado activity. "Linear model approach"

Future work (Post Graduation)

- Further diagnostic work on the role of additional SST anomalies and tornado events

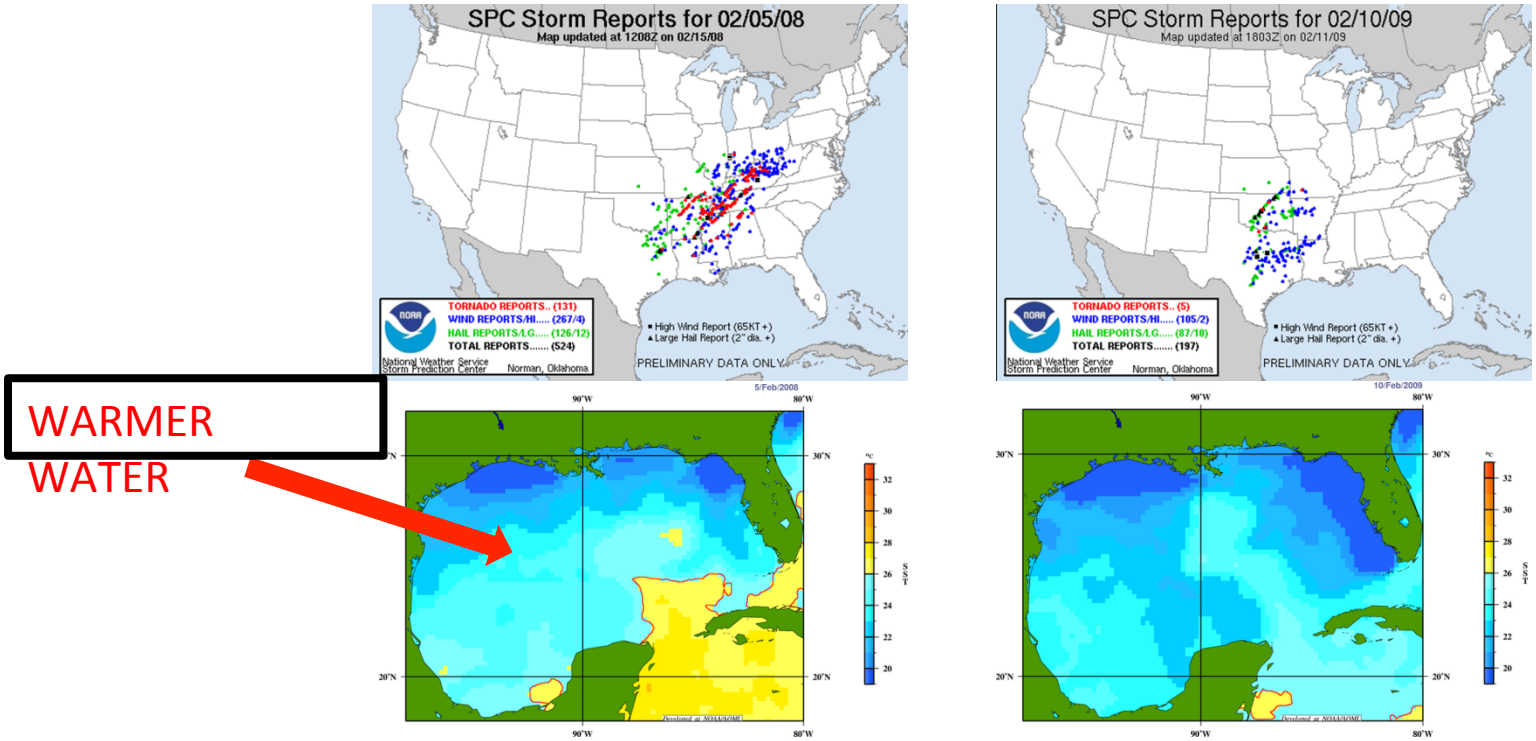




Area of warm SST anomalies off the Pacific Northwest/Gulf of Alaska contributed to an anomalous ridge in the western U.S., leading to persistent California drought and a historically quiet January-April period for tornado outbreaks

Future work (Post Graduation)

- Further diagnostic work on the role of additional SST anomalies and tornado events



SSTs in the Gulf of Mexico were near 1°C higher in February 2008 compared to February 2009 (both LN winter conditions). Tornado outbreaks occurred in both months, but the 2008 outbreak was far more numerous and impactful than in 2009. NAO influence?

Future work (Post Graduation)

- Continued progress toward a 1-6 month seasonal tornado outbreak prediction scheme
- Further develop the results of the atmospheric climatology in Chapter 2 to create an 'atmosphere-based tornado climatology' that helps address the issue of errors in the tornado dataset
- Use that 'atmosphere-based tornado climatology' to assess potential changes in tornado outbreak frequency in future climate simulations