

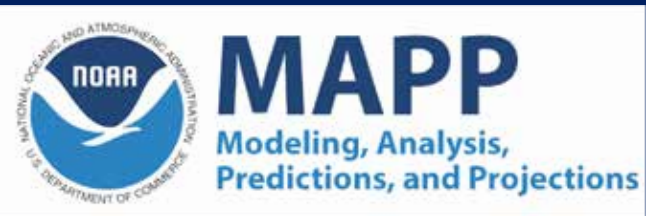
Hybrid Prediction of Weekly Tornado Activity: Utilizing Weather Regimes

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¹University of Illinois at Urbana-Champaign

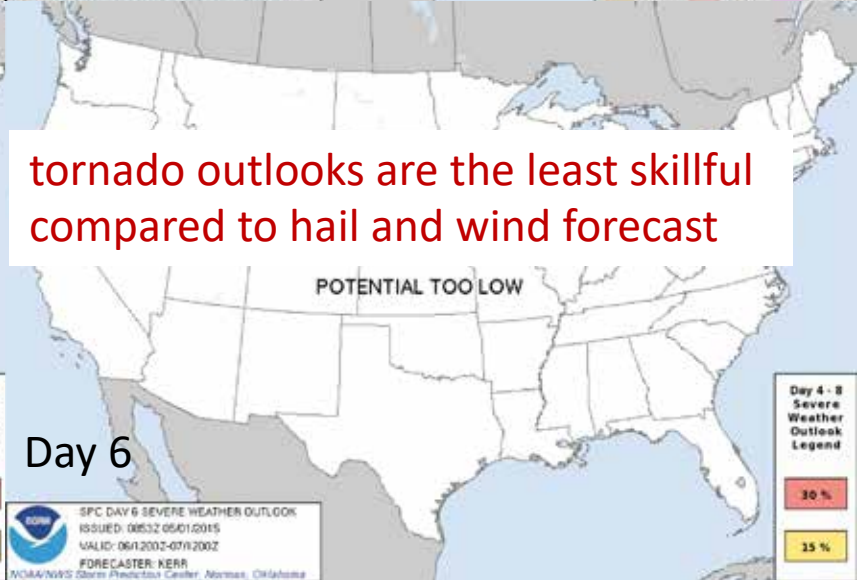
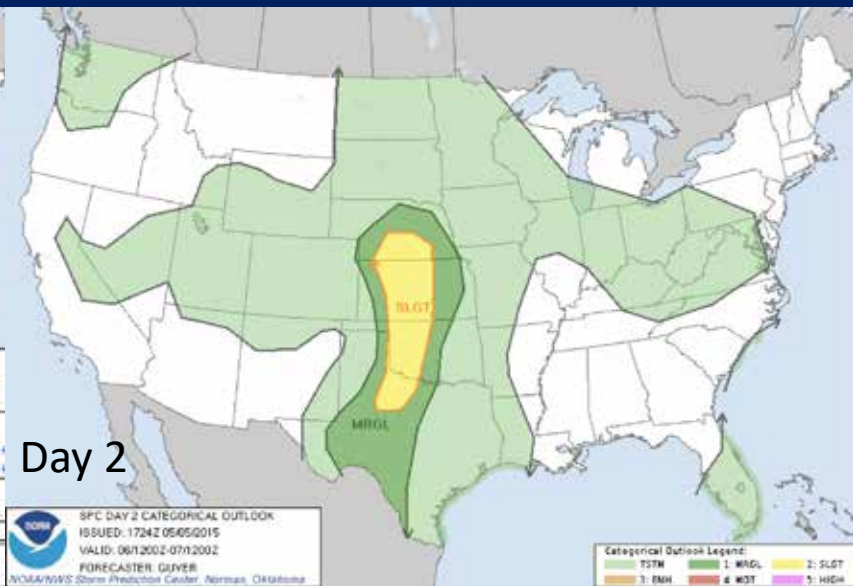
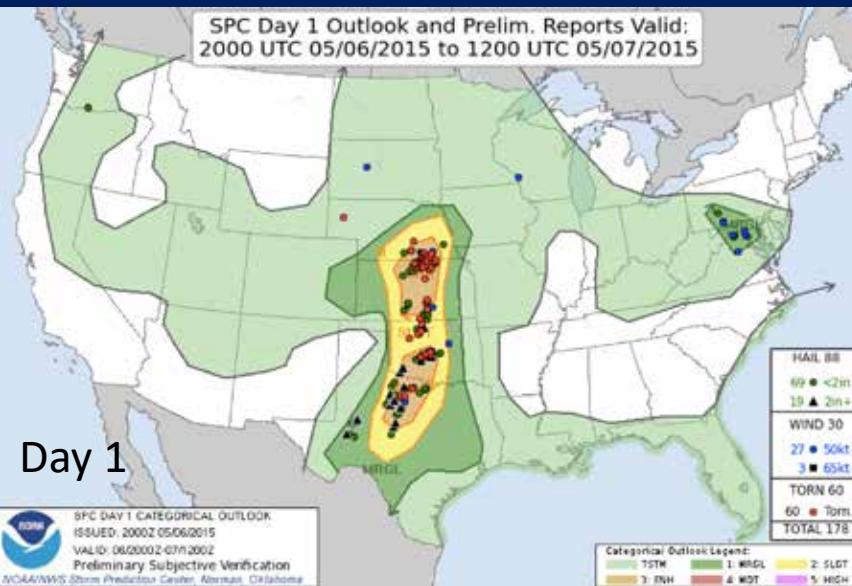
²Climate Prediction Center

See Miller et al. 2020 (GRL):
<https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2020GL087253>



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What is the current predictability limit for severe weather?



Subseasonal to Seasonal Prediction of Tornado Activity

- S2S tornado predictions make use of quantifications of the environmental conditions important for tornado formation (e.g., Brooks et al., 1994; Brooks et al., 2003; Grams et al., 2012; Weisman & Klemp, 1982), such as CAPE and vertical wind shear.
- Low-frequency climate modes, including the ENSO (Allen et al., 2015; Cook & Schaefer, 2008), MJO (Thompson & Roundy, 2013; Tippett 2018) and Global wind oscillation (GWO) (Gensini & Marinaro, 2016; Moore, 2018), modulate tornado activity on the S2S time scale.
- Statistical models have been developed based on these climate modes to predict severe storm activity on the S2S time scale (Baggett et al., 2018; Gensini et al., 2019; Lepore et al., 2017).

Hypothesis

- The ENSO, MJO, and GWO explain limited variability of tornado activity. Tornado outbreaks can still occur even when these low-frequency climate modes suggest an overall inactive time period (Moore et al., 2018).
- Synoptic-scale events strongly modulate the environmental conditions on the shorter time scales and can induce tornado outbreaks even when the climate modes suggest otherwise
- **Hypothesis: Predictability exists for the statistics of synoptic-scale events, and effectively exploiting this source of predictability can improve S2S prediction of tornado activity.**

Weather Regimes

- Weather regimes (WR) are recurrent atmospheric patterns (Rex, 1950; Michelangeli et al., 1995).
- The underlying assumption is that the large-scale atmospheric circulation can be represented by a finite number of states, supported by theoretical work on the existence of multi-equilibria of the climate system (Charney & Devore, 1979).
- Since a WR may last for weeks, its persistence may serve as a source of predictability on the S2S time scale.
- Two questions
 - *How do the weather regimes modulate tornado activity over the United States? -- observational analysis*
 - *Can we exploit the predictable information of WRs in the S2S prediction of tornado activity? – a hybrid model*

Data

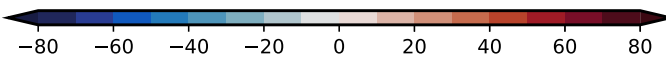
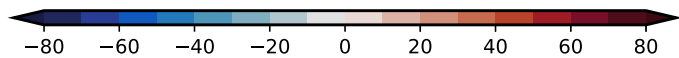
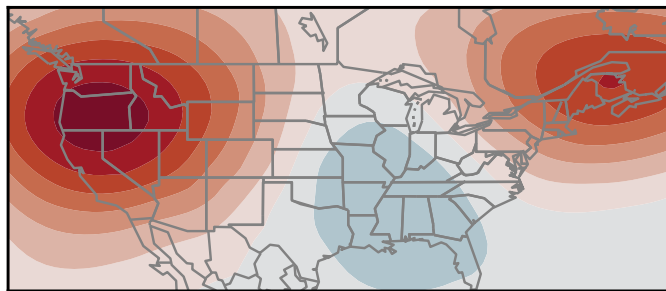
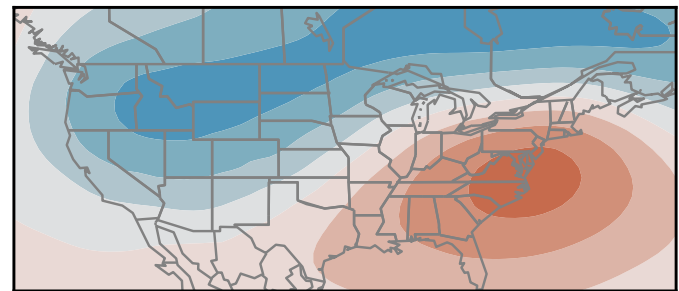
- Tornado reports from SPC website
 - 1990-2019: NEXRAD allows for some quality control of the reports
 - Assign EF1+ reports to a $1^\circ \times 1^\circ$ latitude-longitude grid, smooth by averaging $5^\circ \times 5^\circ$ box
- ERA-Interim reanalysis
 - Daily 500-hPa geopotential height, other variables related to severe storms environments (CAPE, 10-m winds, 500-hPa winds, etc.)
- Reforecast produced from the ECMWF S2S model
 - 11 ensemble members (1 control and 10 perturbations)
 - Lead time out to 46 days
 - Twenty years (1998-2017)
- We focus on **May**, the peak season for tornado activity, but the findings are also valid for March and April.

Part I: How do the weather regimes modulate tornado activity over the United States?

May ERAI WR

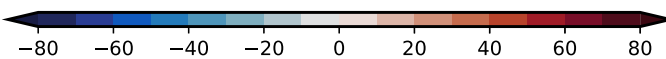
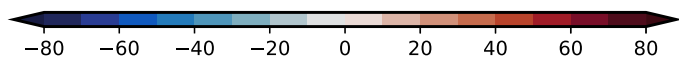
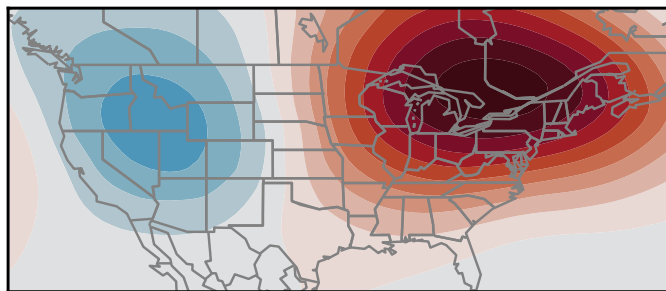
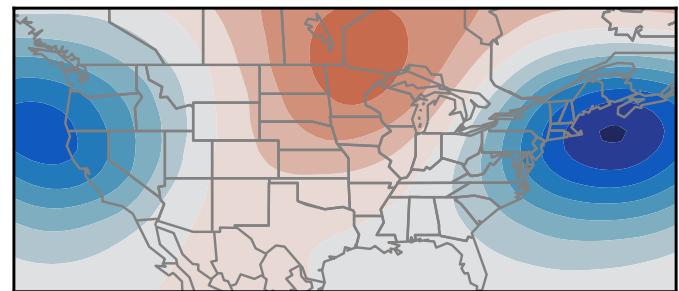
WR 1 (24.8%)

WR 2 (20.4%)

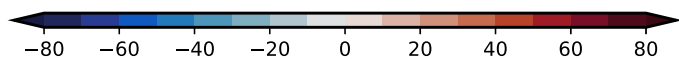
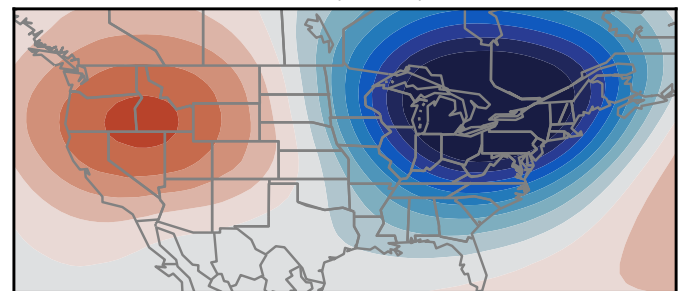


WR 3 (19.7%)

WR 4 (18.5%)



WR 5 (16.6%)



➤ **K-Means Clustering** following Lloyd's algorithm applied to daily 500-hPa GH over (24N-55N, 130W-60W)

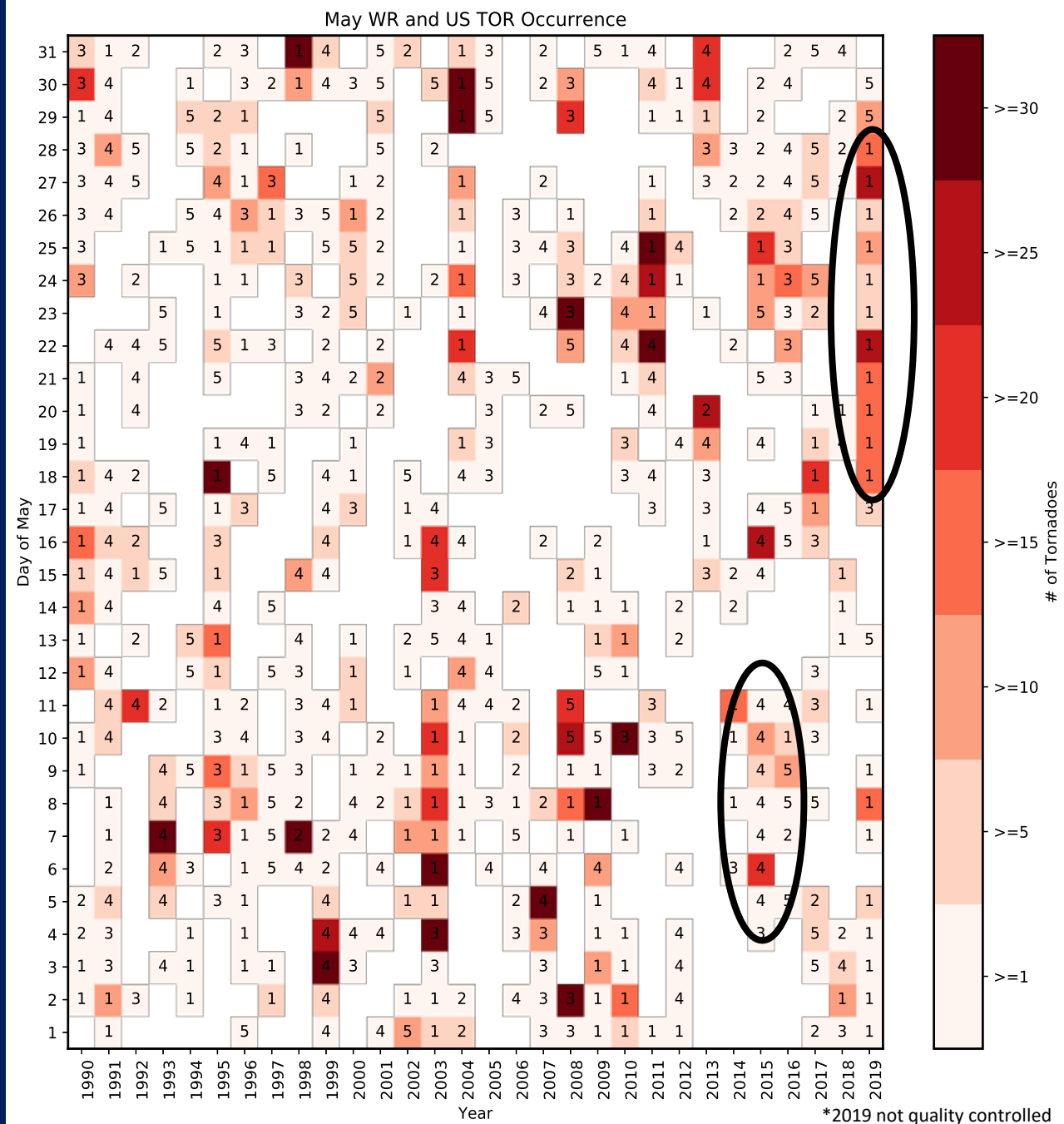
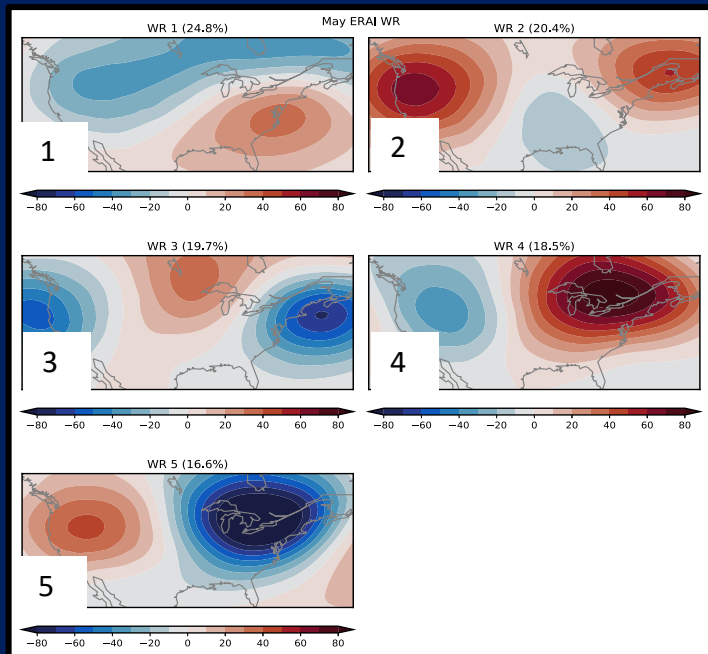
➤ Prescribed **5 regimes** following the elbow method

5 weather regimes

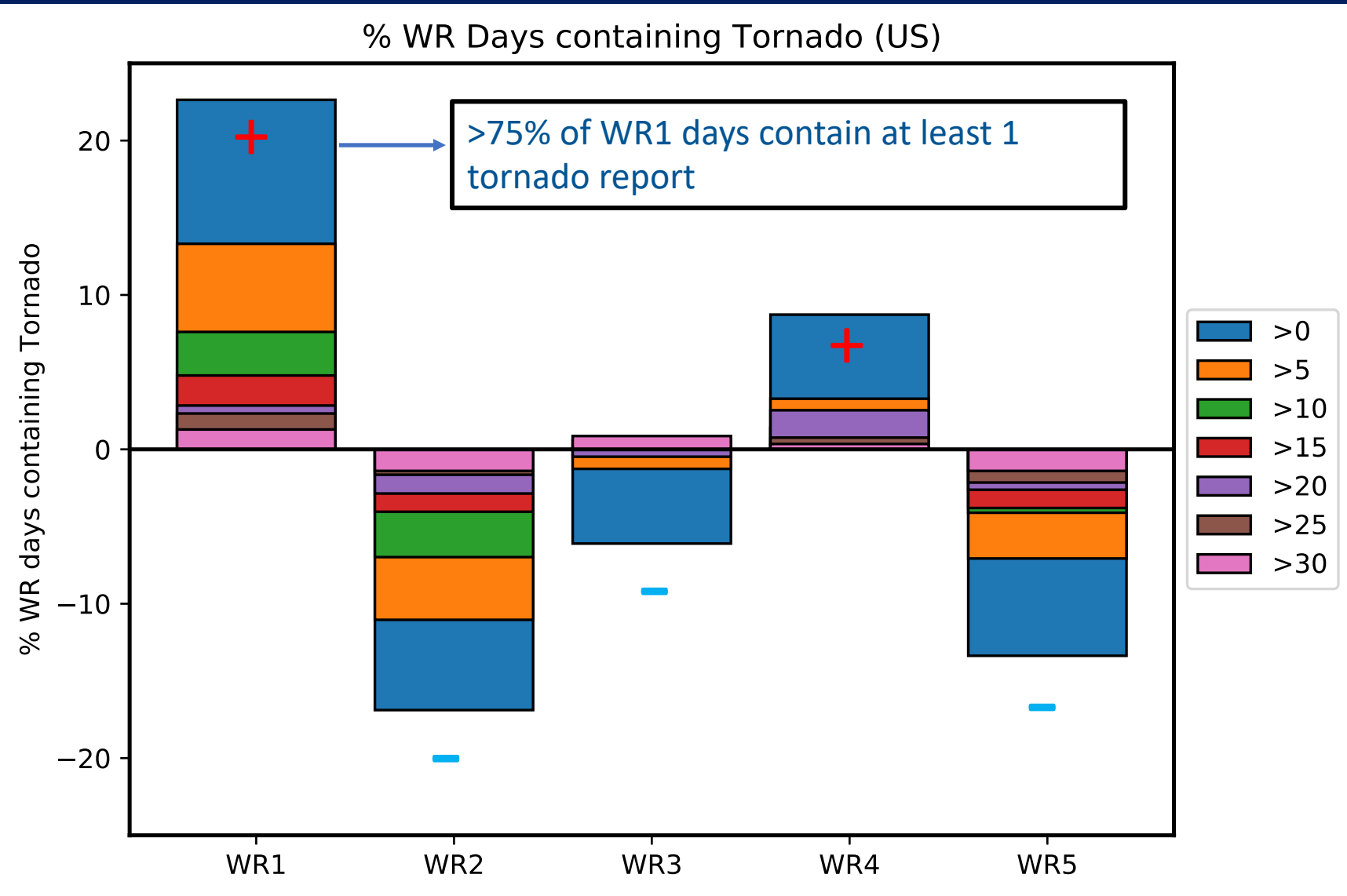
- Southeastern ridge (24.8%)
- Ridge-Trough-Ridge (20.4%)
- Trough-Ridge-Trough (19.7%)
- Trough-Ridge (18.5%)
- Ridge-Trough (16.6%)

May weather regimes and US tornado occurrence

number: Weather Regime Number
color: number of tornadoes per day



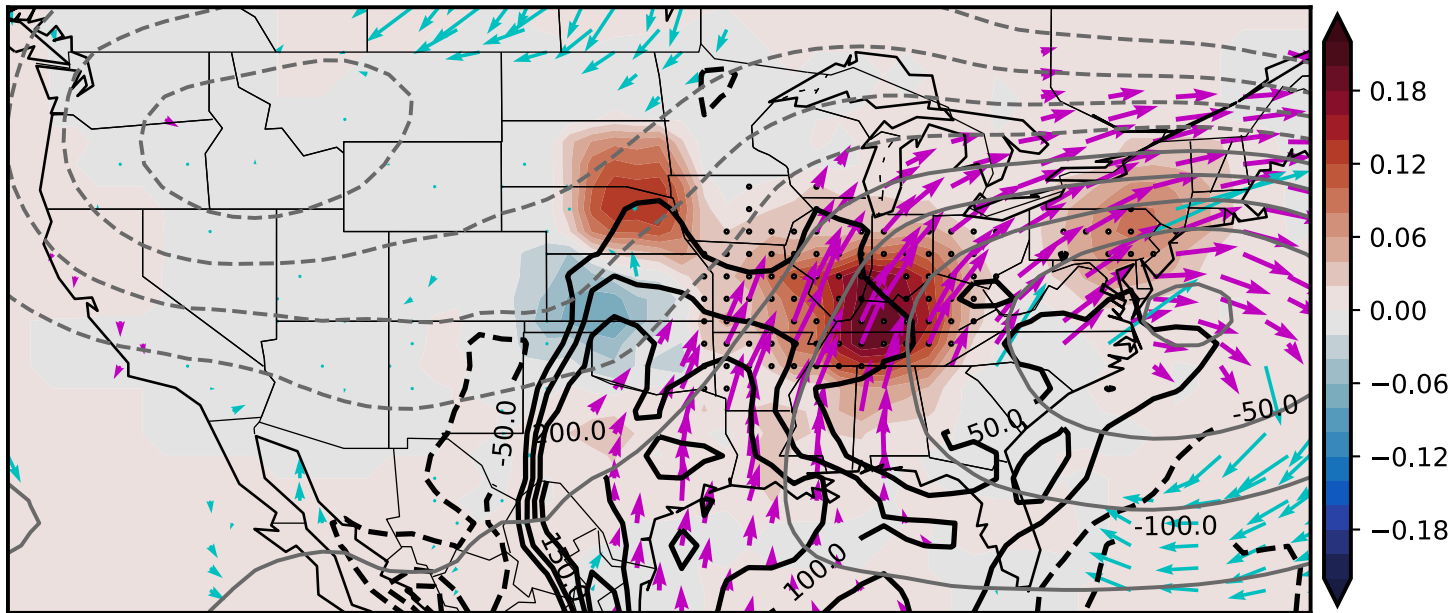
% of WR days containing \geq a tornado report relative to climatology



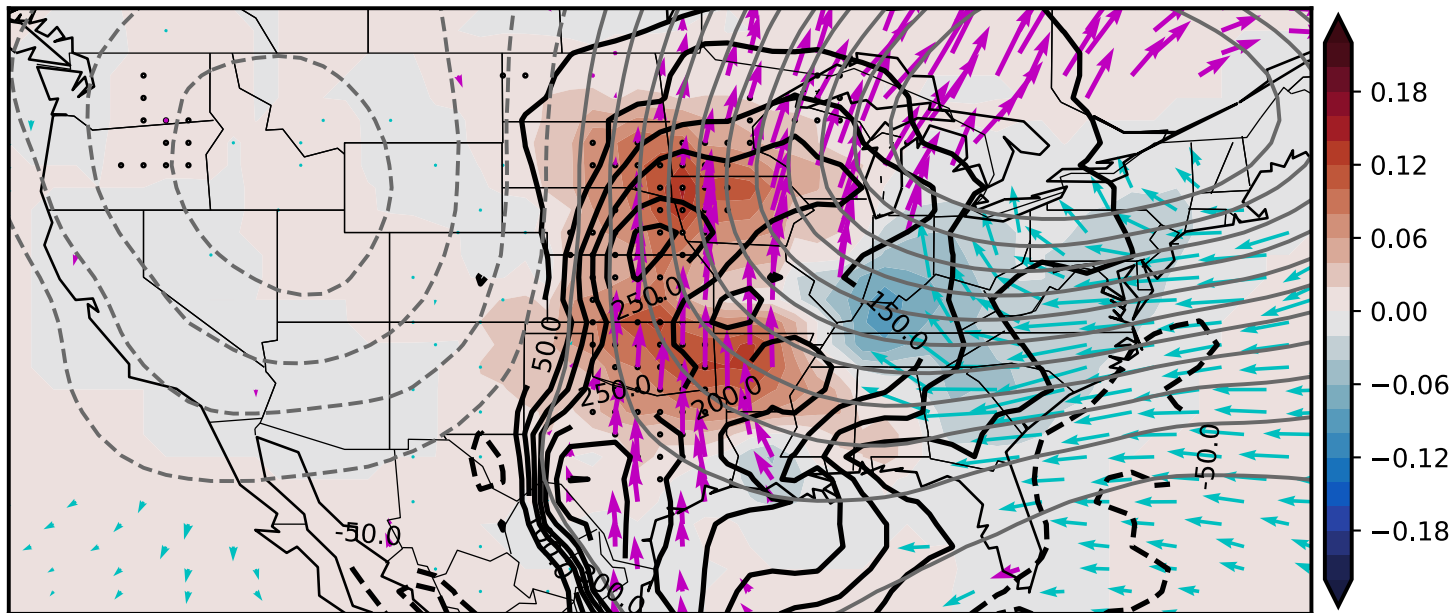
Climatology

% of Days with Tornado	
	US
>0 TORS	54.73
>5 TORS	17.10
>10 TORS	8.49
>15 TORS	5.05
>20 TORS	3.87
>25 TORS	2.15
>30 TORS	1.40

WR1



WR4

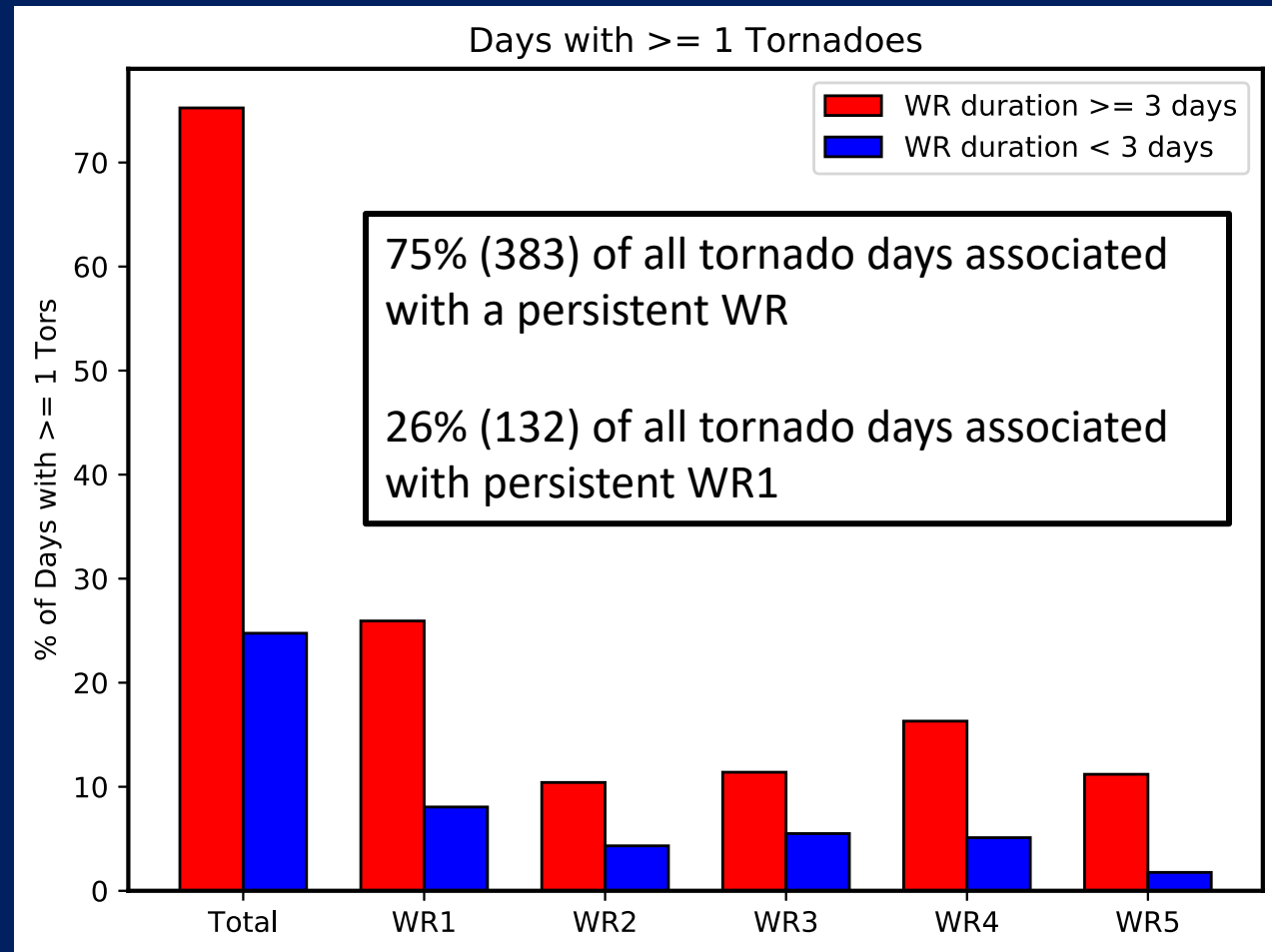


- Z500 (gray contours)
- Tornado Frequency Anomalies (Shading)
- CAPE Anomalies (thick black contours)
- 10-m to 900-hPa Wind Shear: Teal (magenta) vectors are where S900 magnitude is significantly lower (higher) than climatology.

- WR1 and WR4
 - Significant increase in CAPE and Wind Shear → increasing tornado occurrence

Large percentage of tornado days are associated with persistent WRs (WR lasting for 3 days or longer).

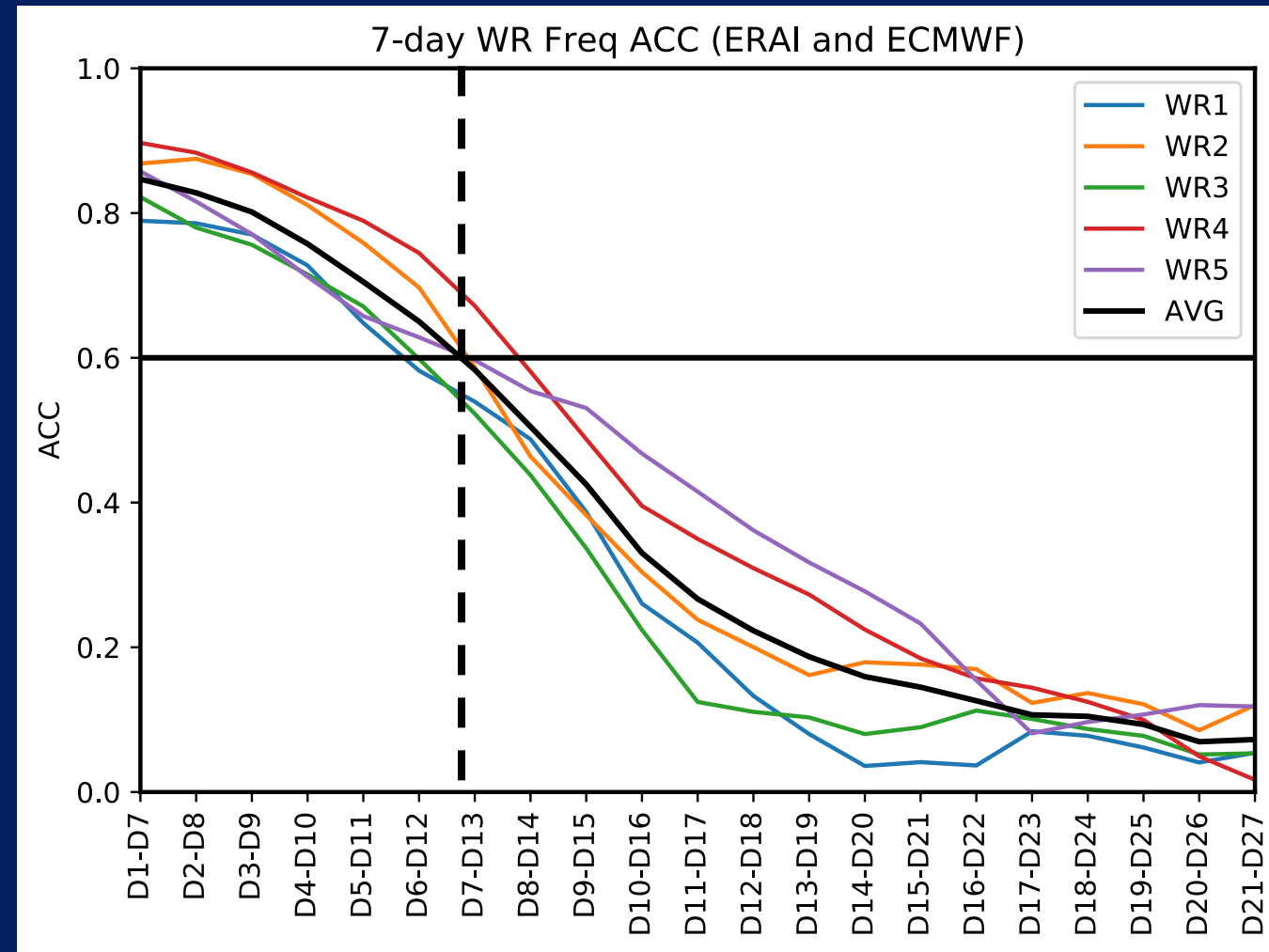
509 Tornado Days



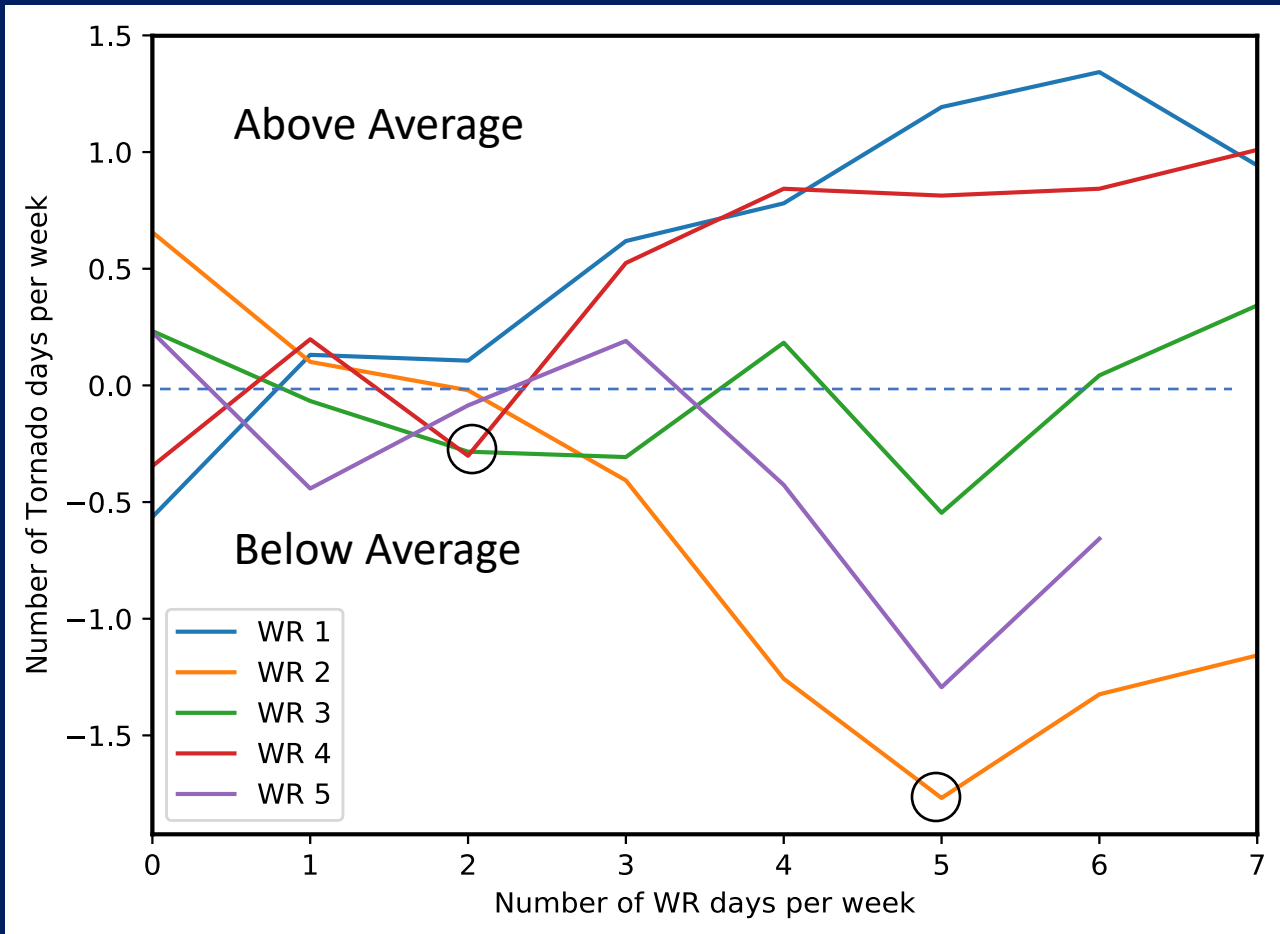
Part II: Can we exploit the predictable information of WRs in the extended-range prediction of tornado activity?

Hybrid prediction, using model predicted WR Frequency, relies on prediction skill of WRs

- ECMWF reproduces the spatial patterns of the WRs reasonably well.
- Calculated the 7-day WR frequency separately for each ensemble member, and then take the ensemble average of WR frequency
- ACC is calculated between observations and average of ensemble members frequencies



Hybrid model to predict weekly tornado activity

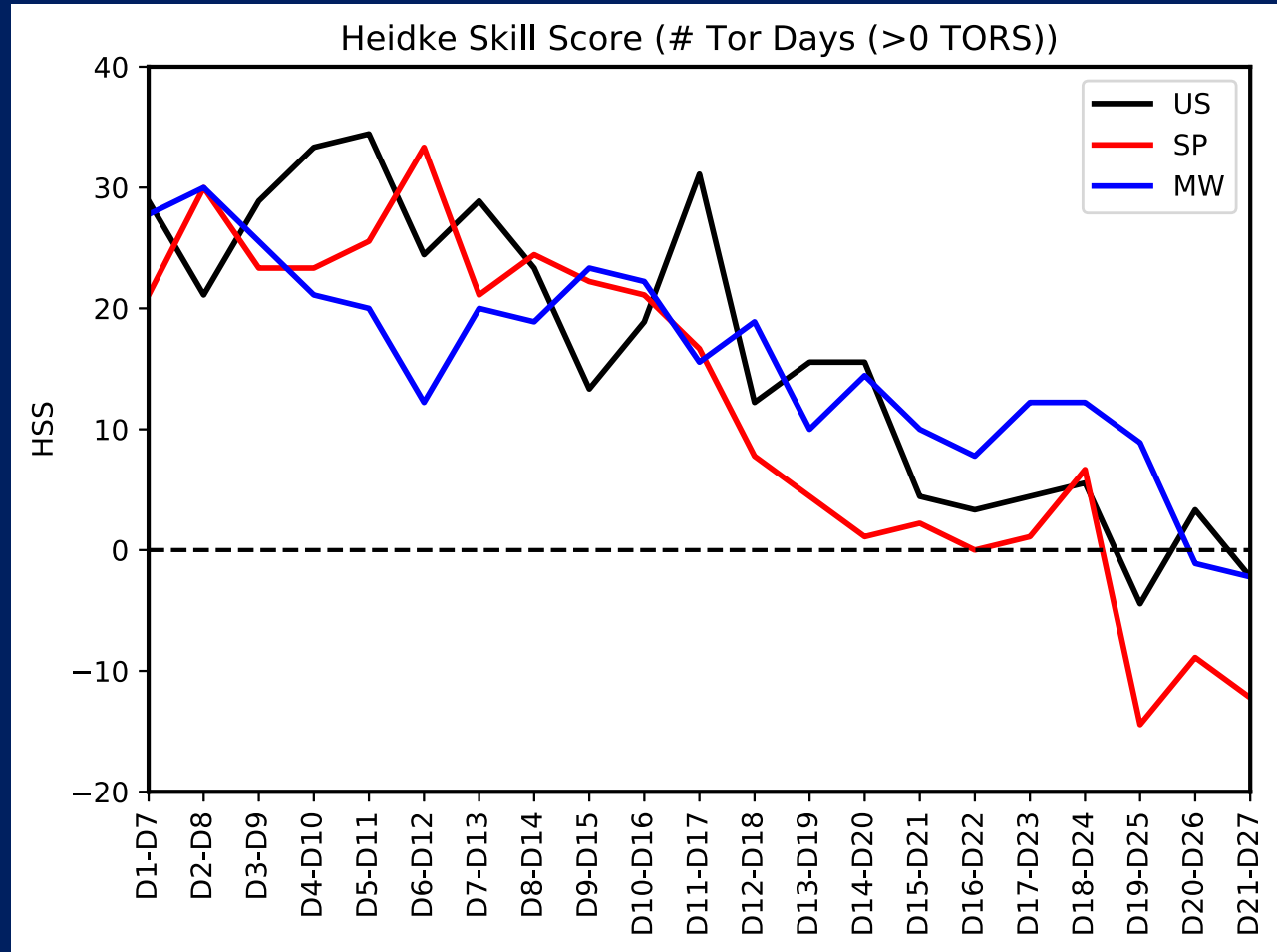


1. Calculate the number of tornado days as a function of WR persistence
2. Calculate the weekly frequency of model predicted weather regimes
3. Predicted tornado activity is based on distributions of training data set (leave-one-out) as a function of WR and number of WR days per week

For example, if the model predicts Week 1 to contain 5 WR2 days and 2 WR4 days, the model predicts ~ 2.1 (-1.8 - 0.3) tornado days below normal activity.

Positive HSS out to week 3-4

- A leave-one year-out method is employed to assess the prediction skill.
- The Heidke Skill Score (HSS) for 2-tier prediction is calculated (above and below average)

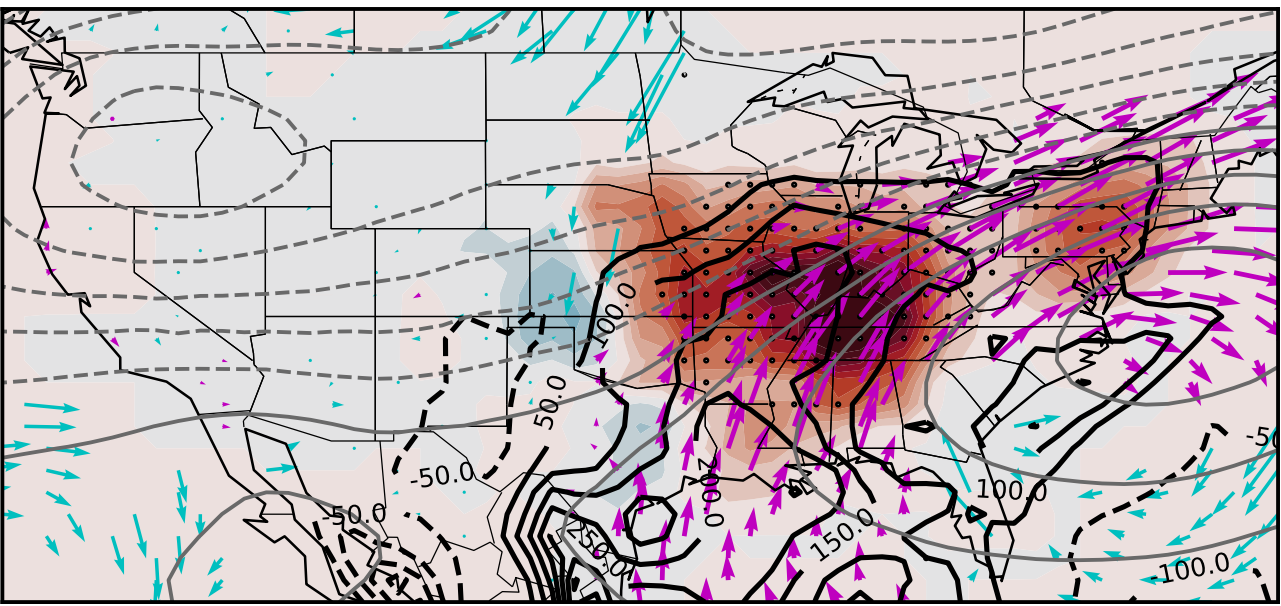
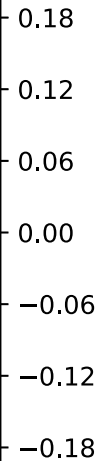


Conclusions

- Large-scale weather regimes strongly modulate tornado activity
- Persistent WRs are associated with large percentage of tornado outbreak days
- Hybrid prediction using dynamic model predicted weather regime frequency and an empirical approach has skill better than climatology out to week 3
- Persistent weather regimes emphasized in this study, along with the forecast of opportunity associated with low-frequency climate modes, can be a valuable source of tornado predictability

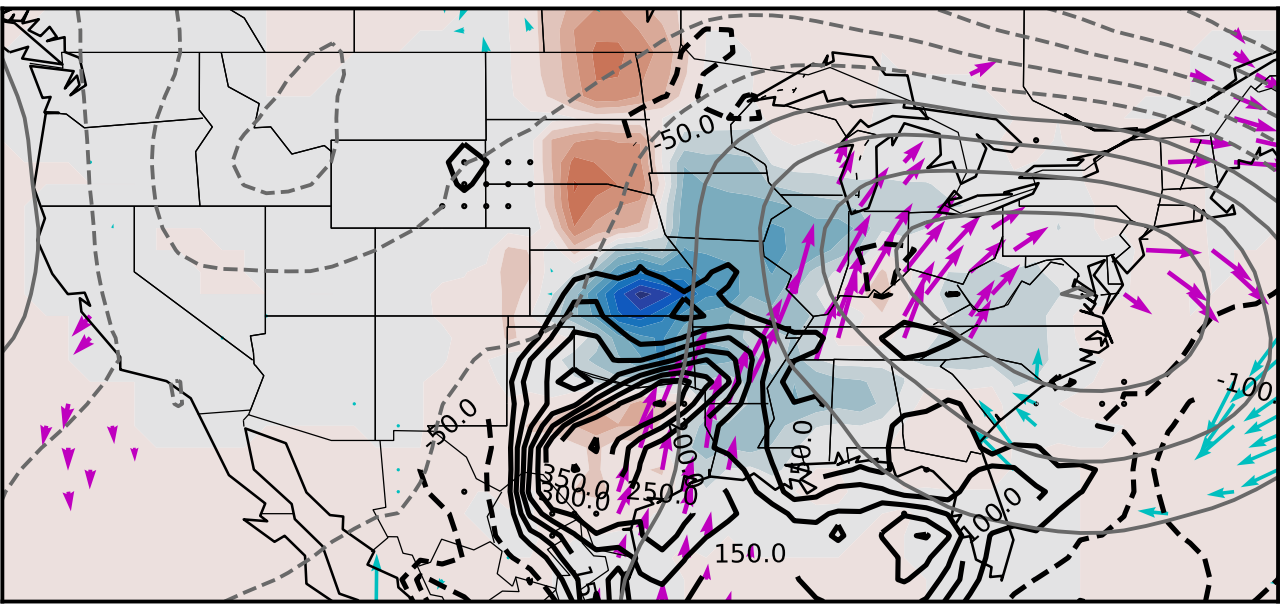
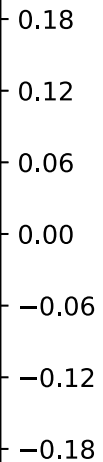
WR1

Tornado Frequency Anomalies (Shading)
CAPE Anomalies (Contours)
10-m to 900-hPa Wind Shear (vectors)



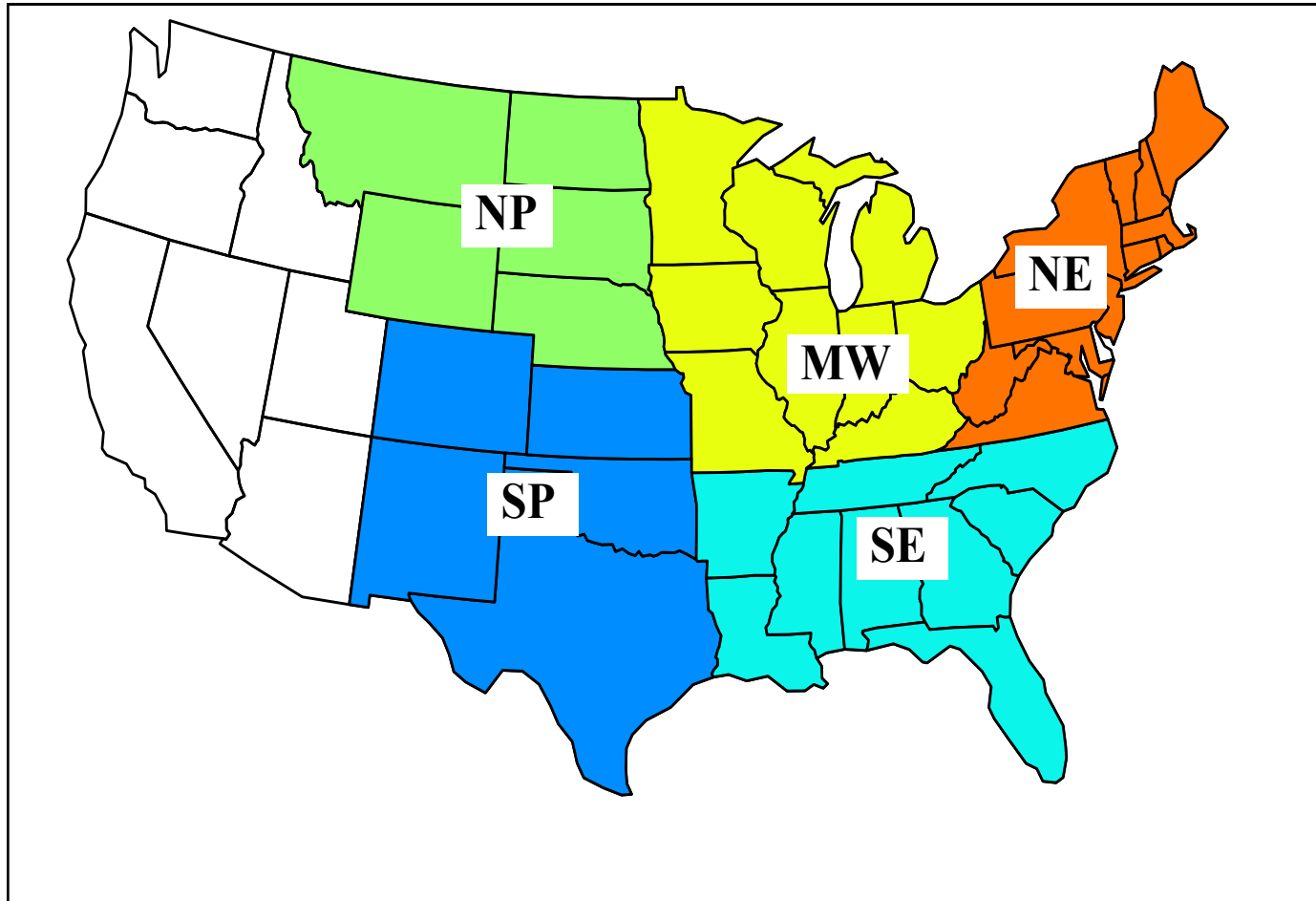
Events persisting 3 days or longer

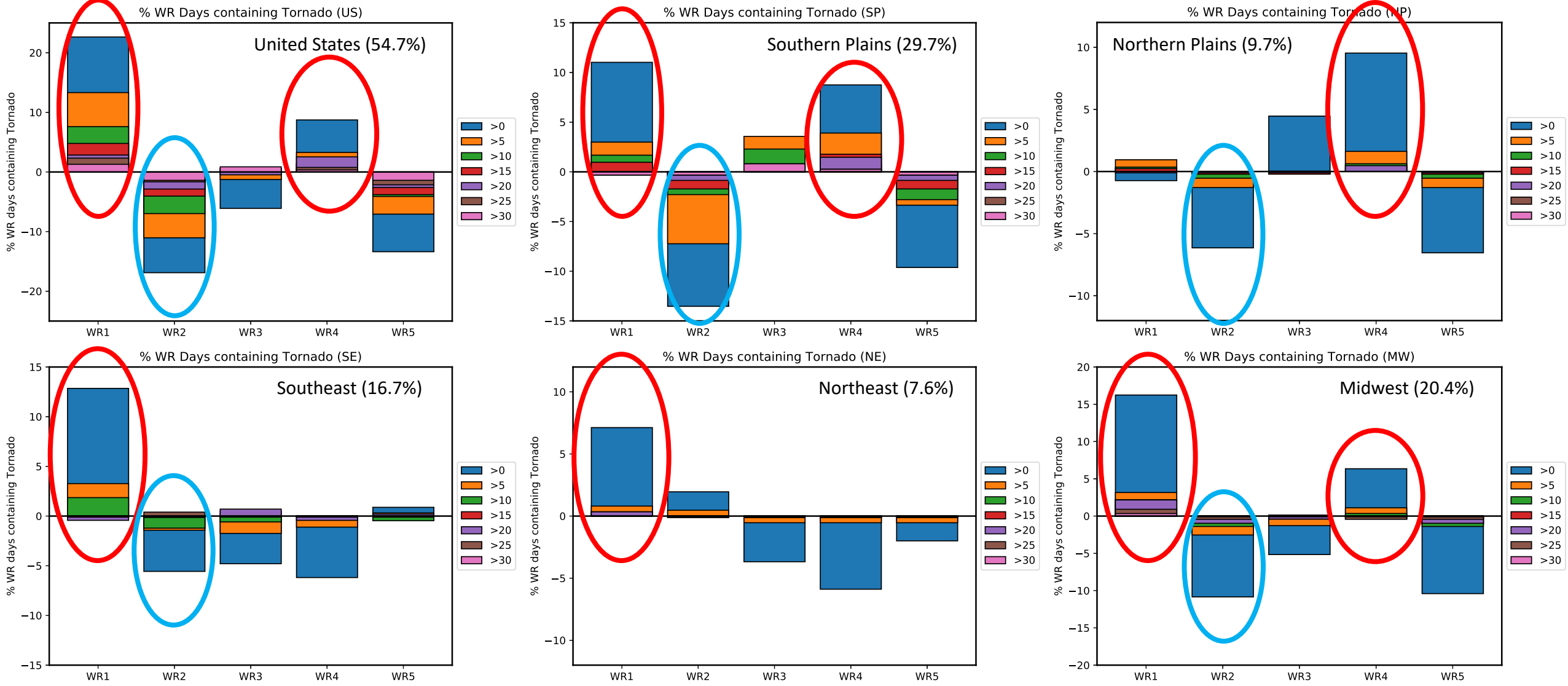
WR1



Non-persisting events

Defined Regions





% of WR days containing a tornado relative to climatology

Hybrid prediction, using model predicted WR Frequency, relies on model ability to produce WR

