Hybrid Prediction of Weekly Tornado Activity: Utilizing Weather Regimes

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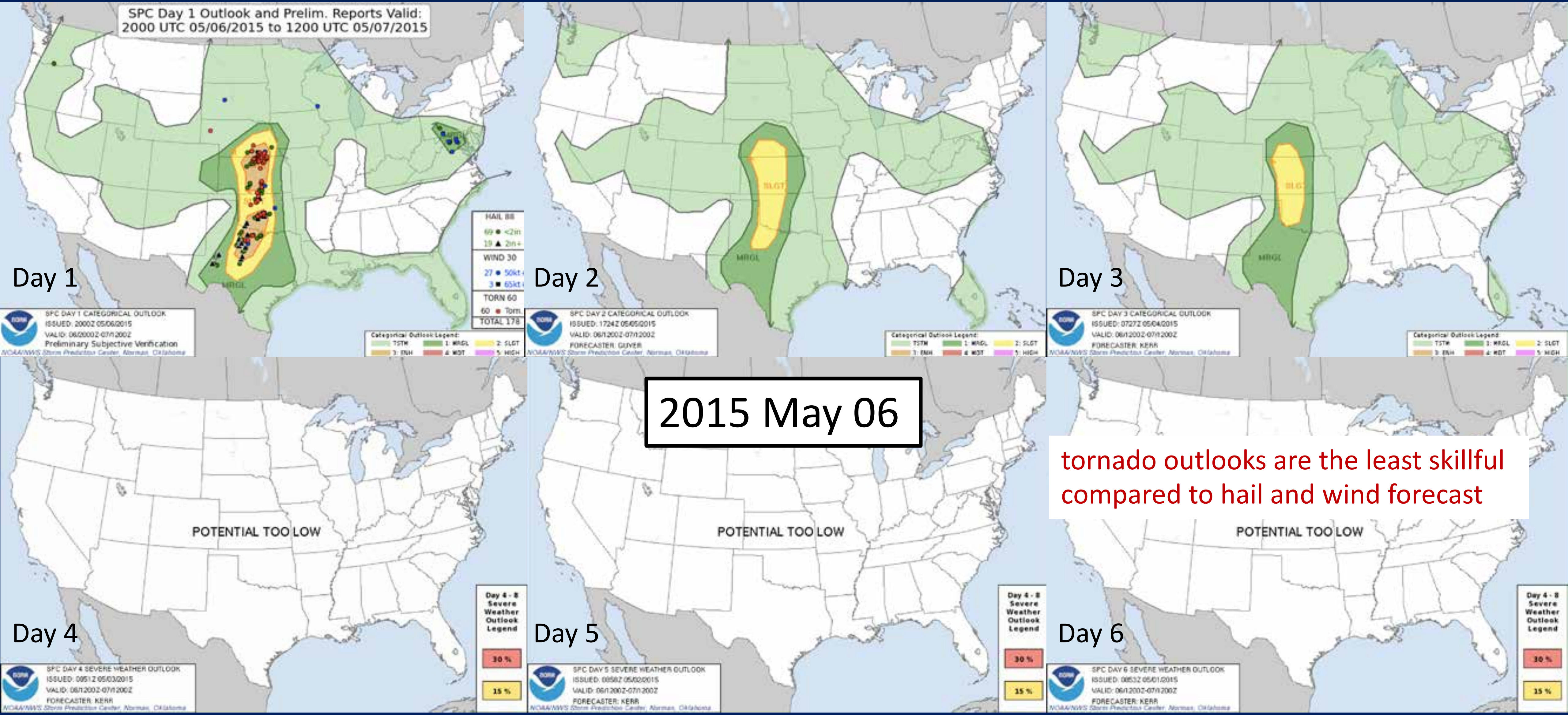
What is the current predictability limit for severe weather?



2015 May 06

tornado outlooks are the least skillful compared to hail and wind forecast

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.

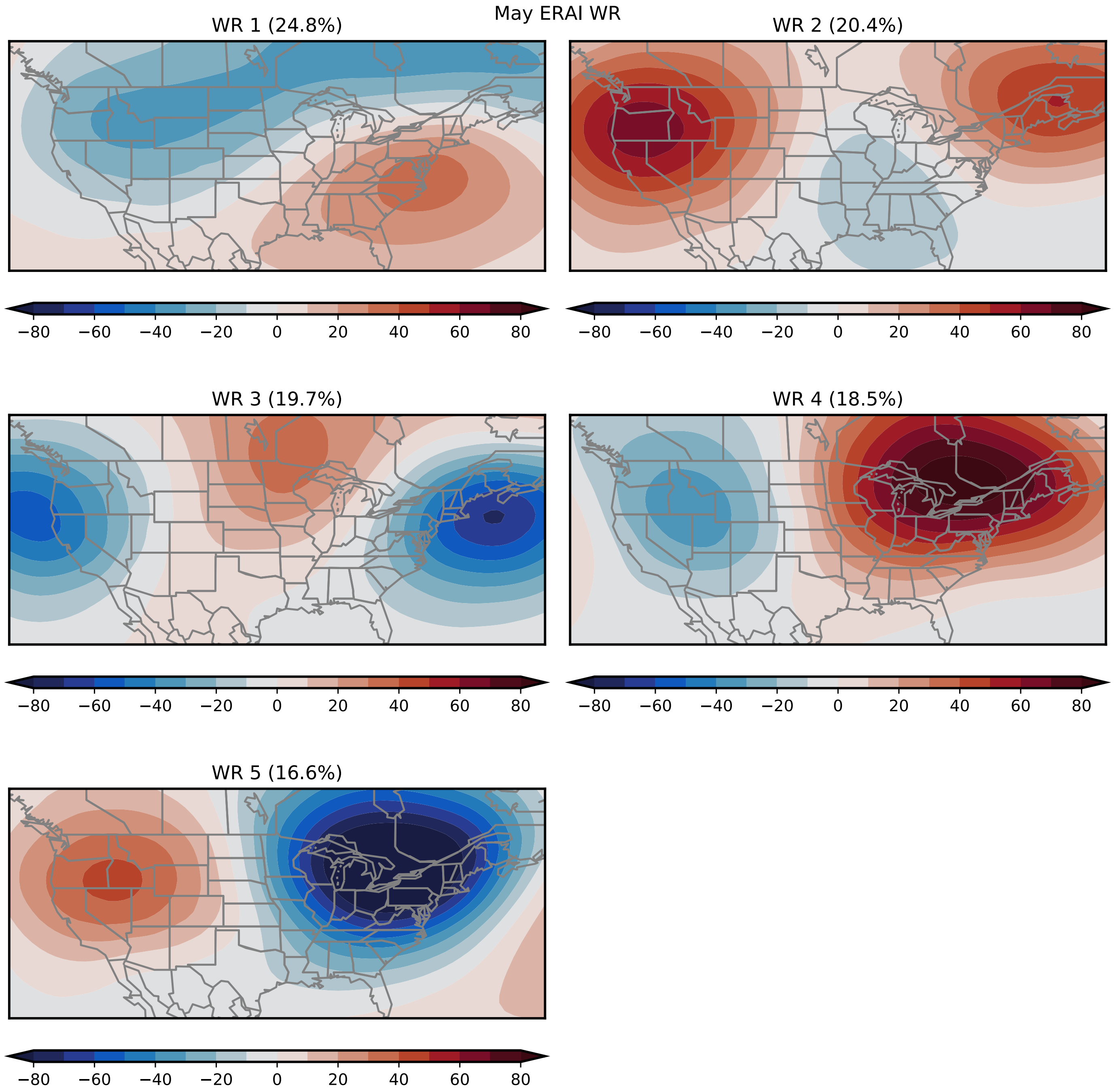
Weather Regimes

- 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°x 1° latitude-longitude grid, smooth by averaging 5°x 5° 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?



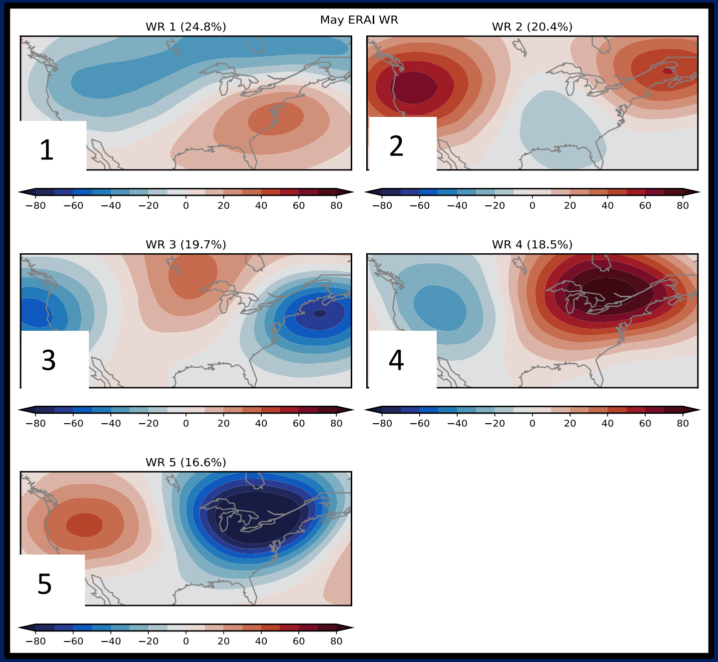
- **K-Means Clustering** following Lloyd's algorithm applied to daily 500-hPa GH over (24N-55N, 130W-60W)
- Prescribed **5 regimes** following the elbow method

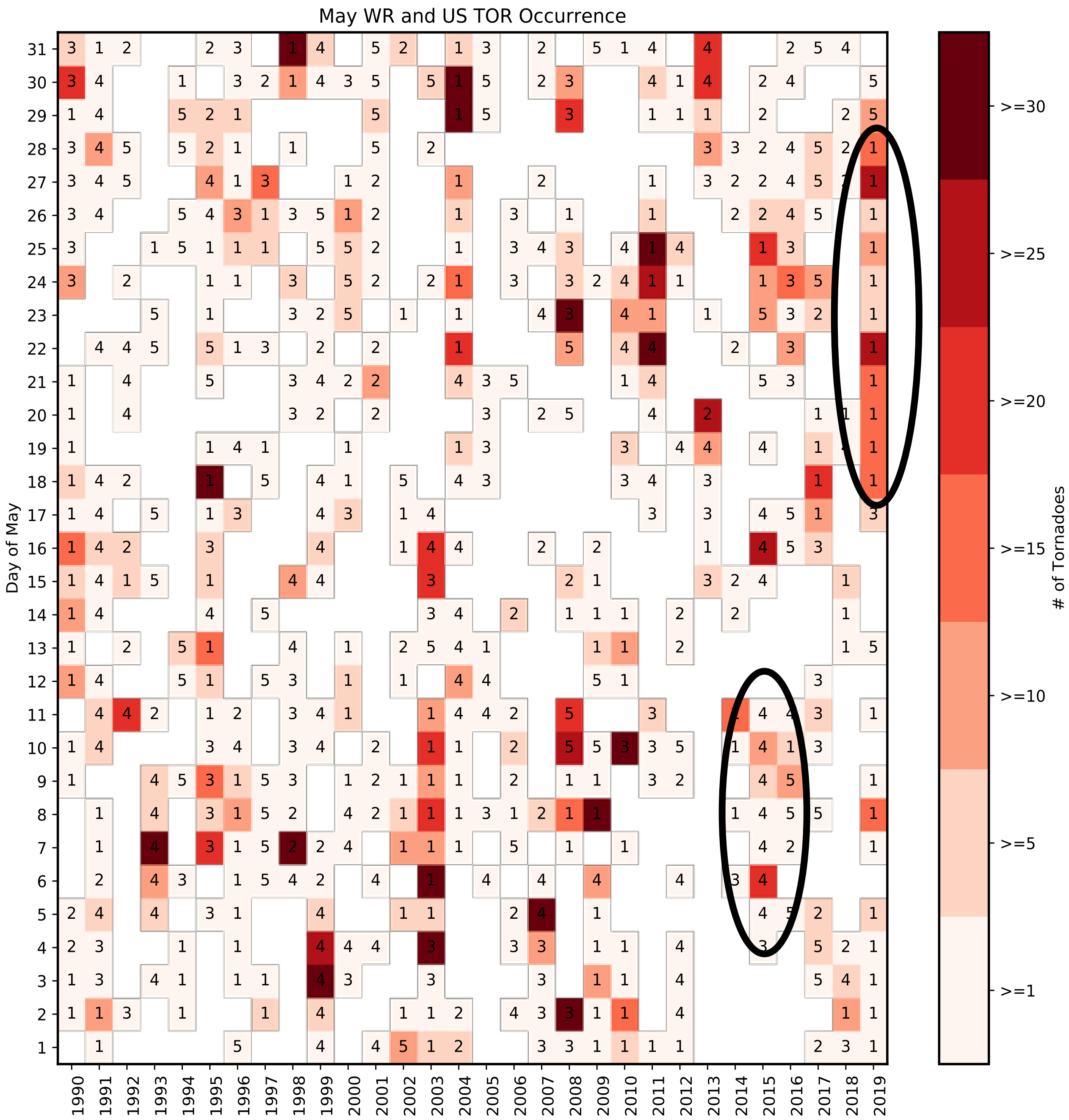
5 weather regimes

- 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

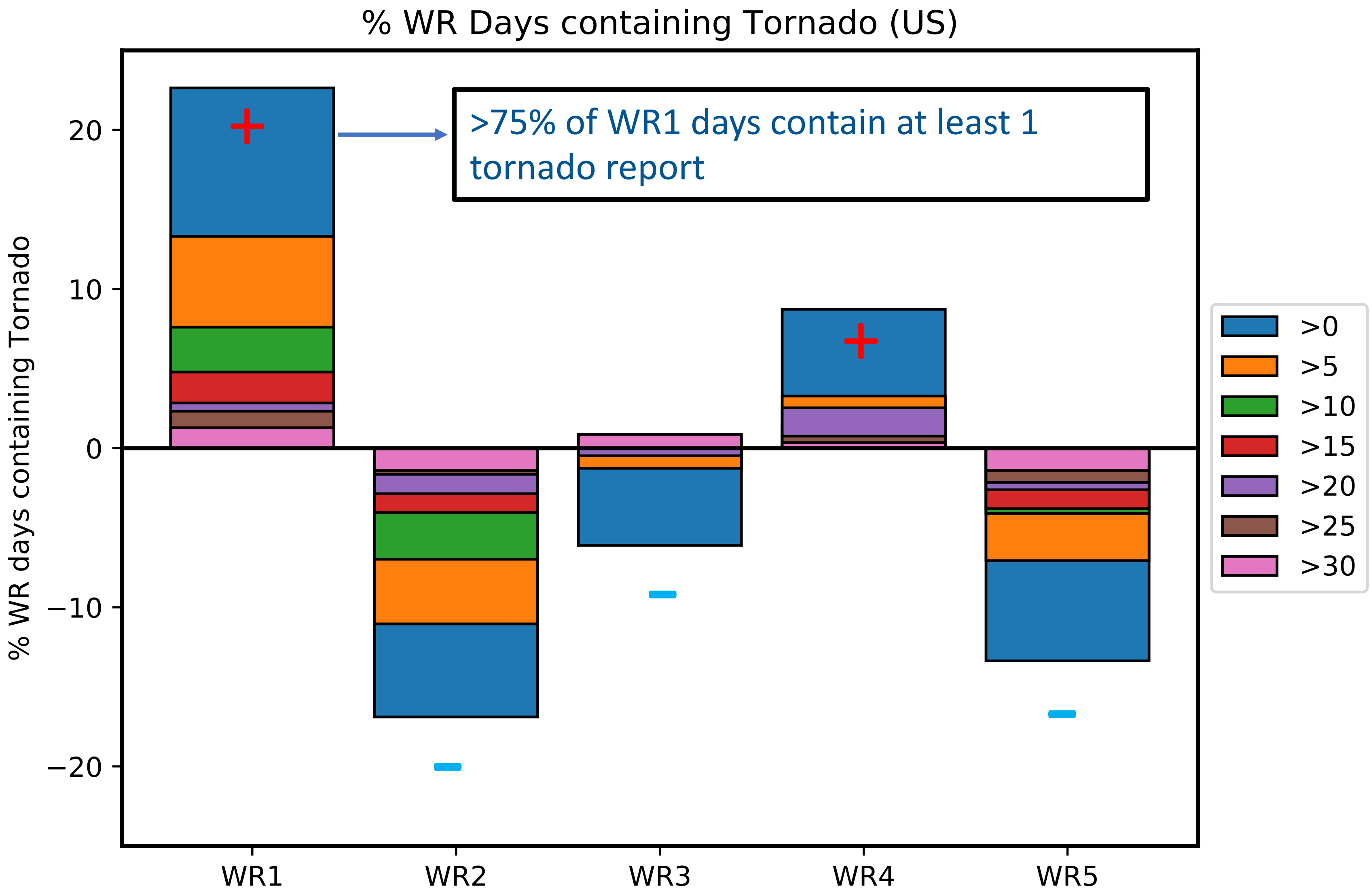
number: Weather Regime Number
color: number of tornadoes per day





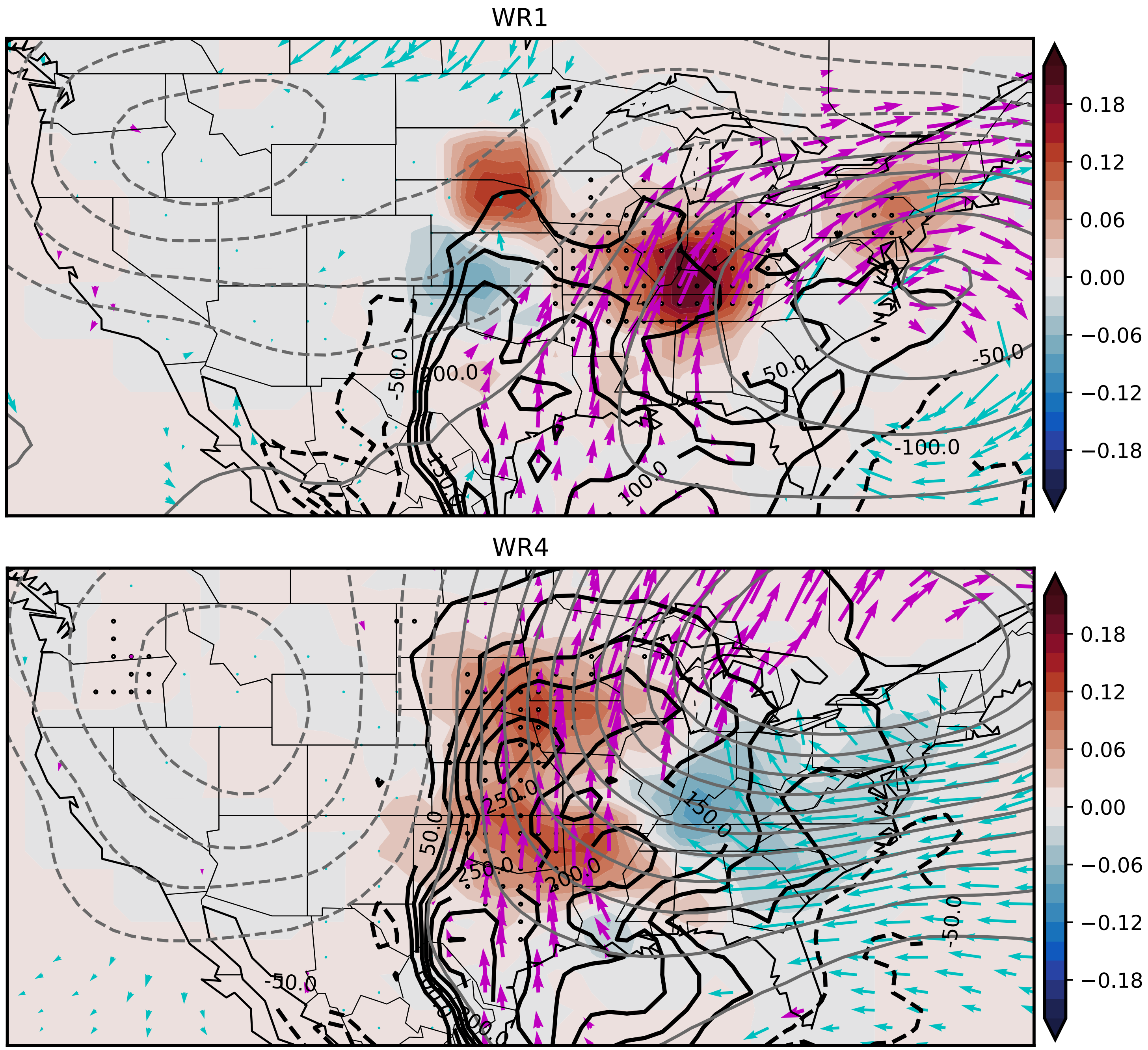
*2019 not quality controlled

% of WR days containing >= 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

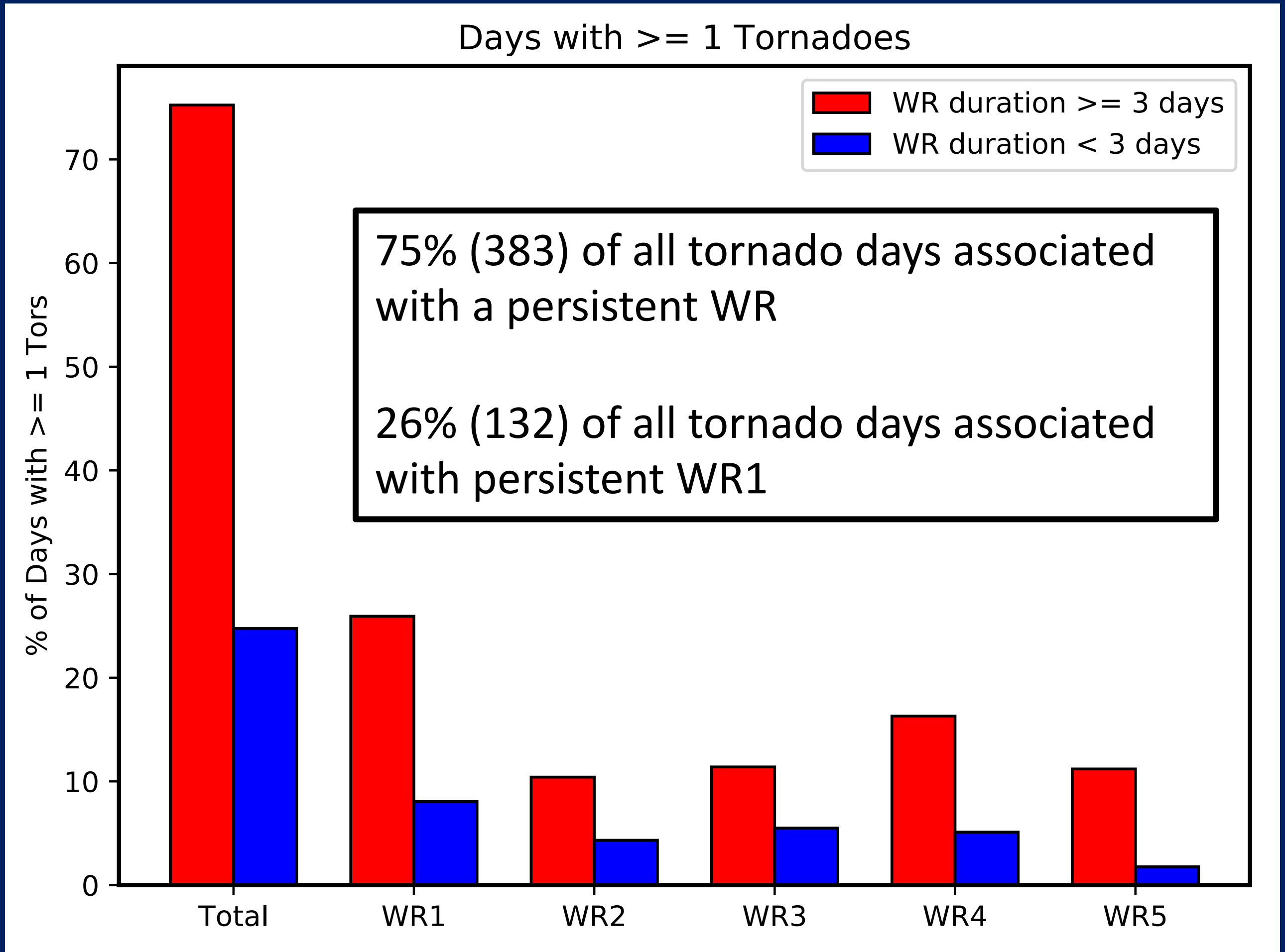


- Z500 (gray contours)
- Tornado Frequency Anomalies (Shading)
- CAPE Anomalies (thick black contours)
- 10-m to 900-hPa Wind Shear: Teal (magenta) vectors are where S900 magnitude is significantly lower (higher) than climatology.

- 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).

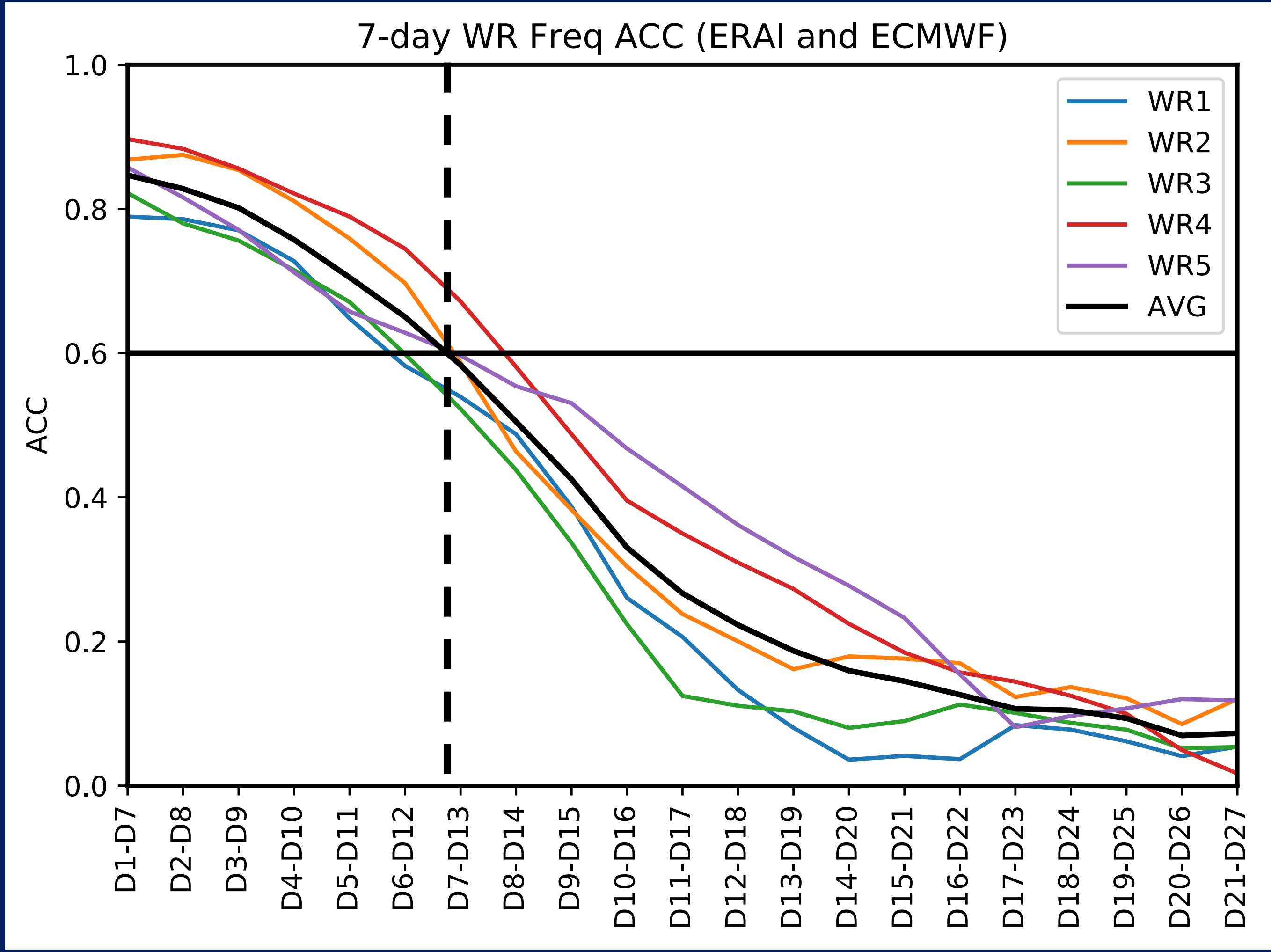
509 Tornado Days



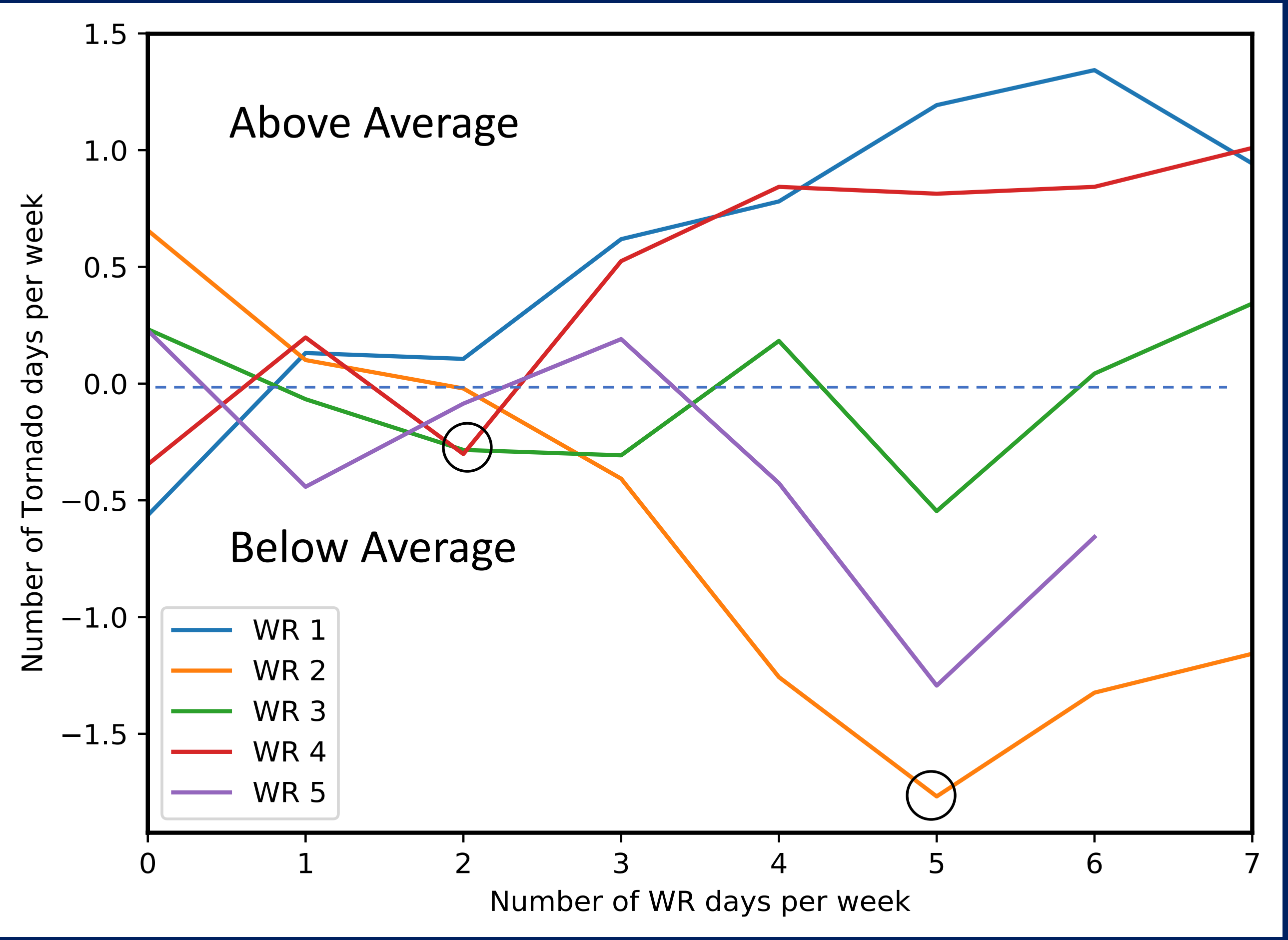
Part II: Can we exploit the predictable information of WRs in the extended-range prediction of tornado activity?

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

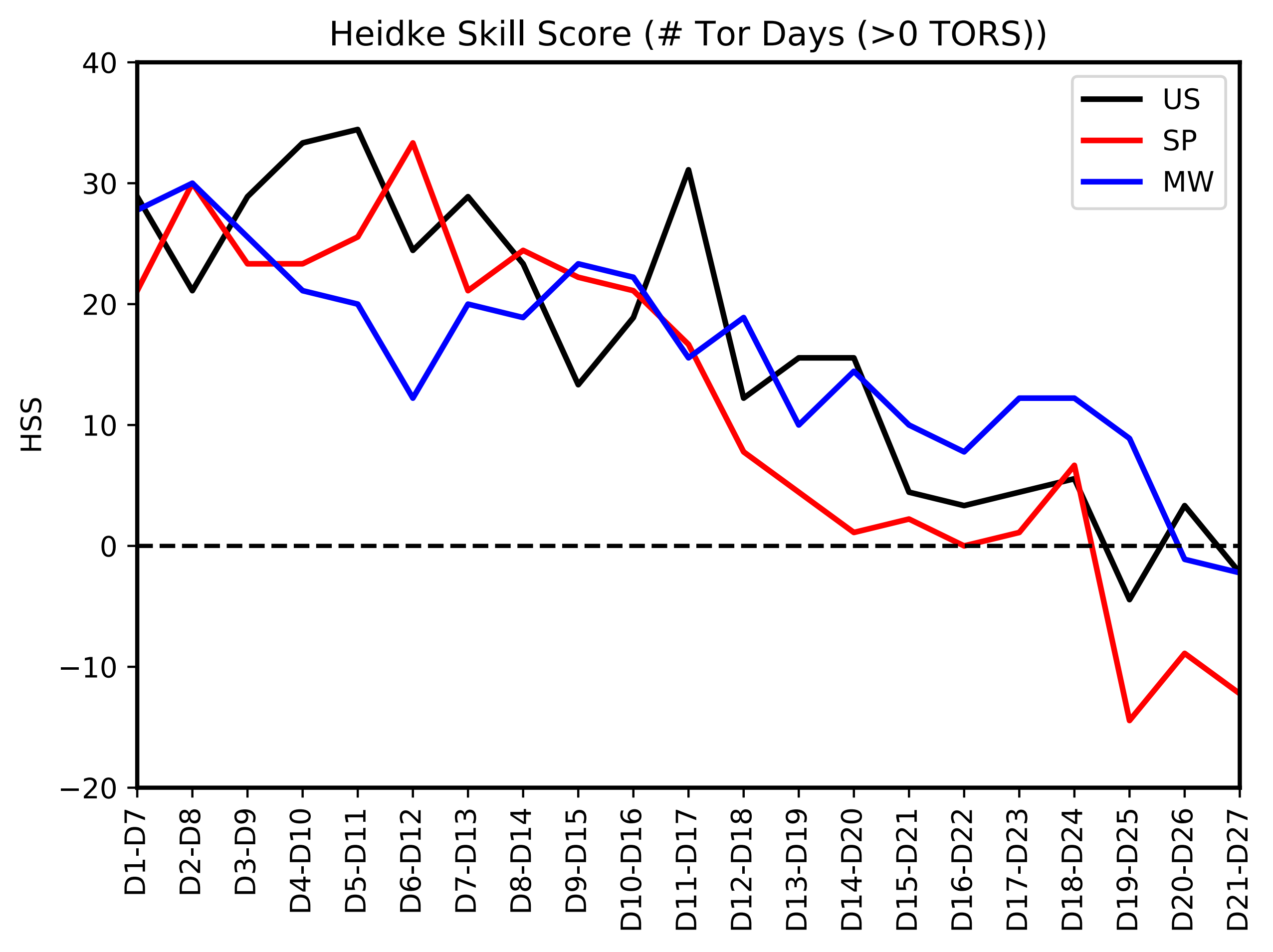


1. Calculate the number of tornado days as a function of WR persistence
2. Calculate the weekly frequency of model predicted weather regimes
3. Predicted tornado activity is based on distributions of training data set (leave-one-out) as a function of WR and number of WR days per week

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

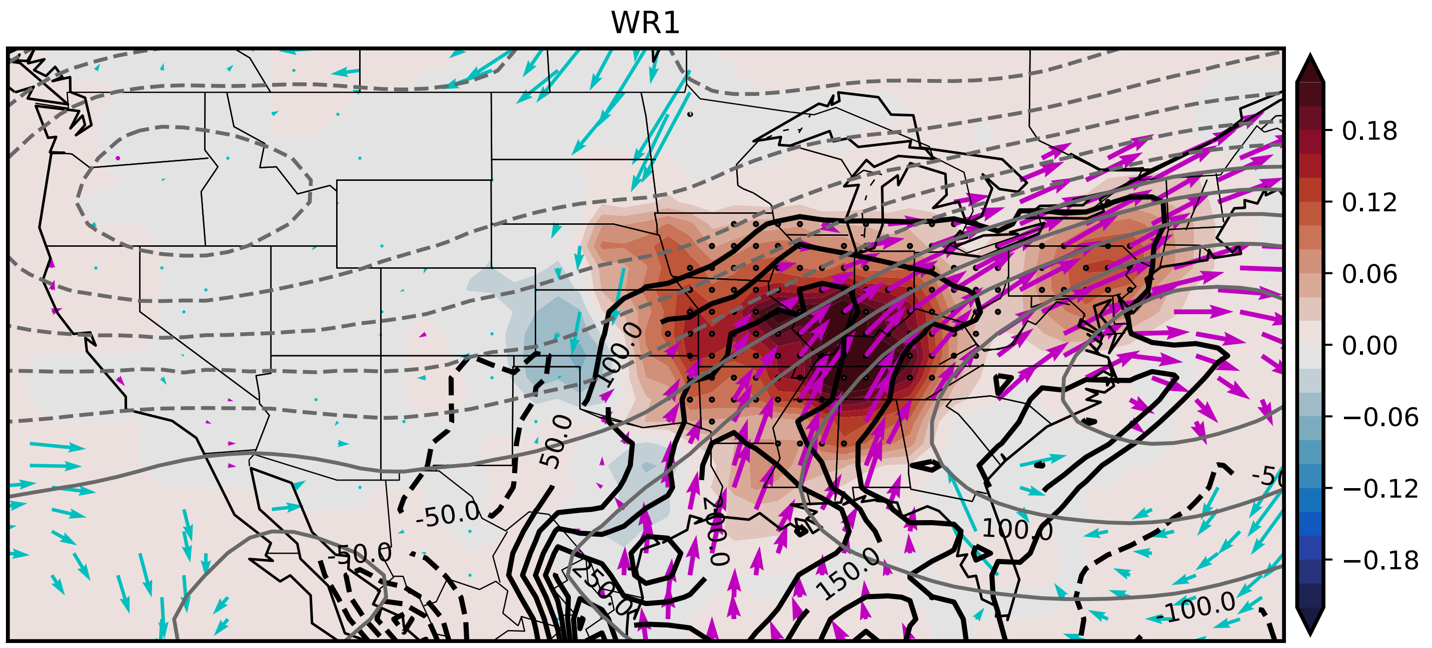
- A leave-one year-out method is employed to assess the prediction skill.
- The Heidke Skill Score (HSS) for 2-tier prediction is calculated (above and below average)



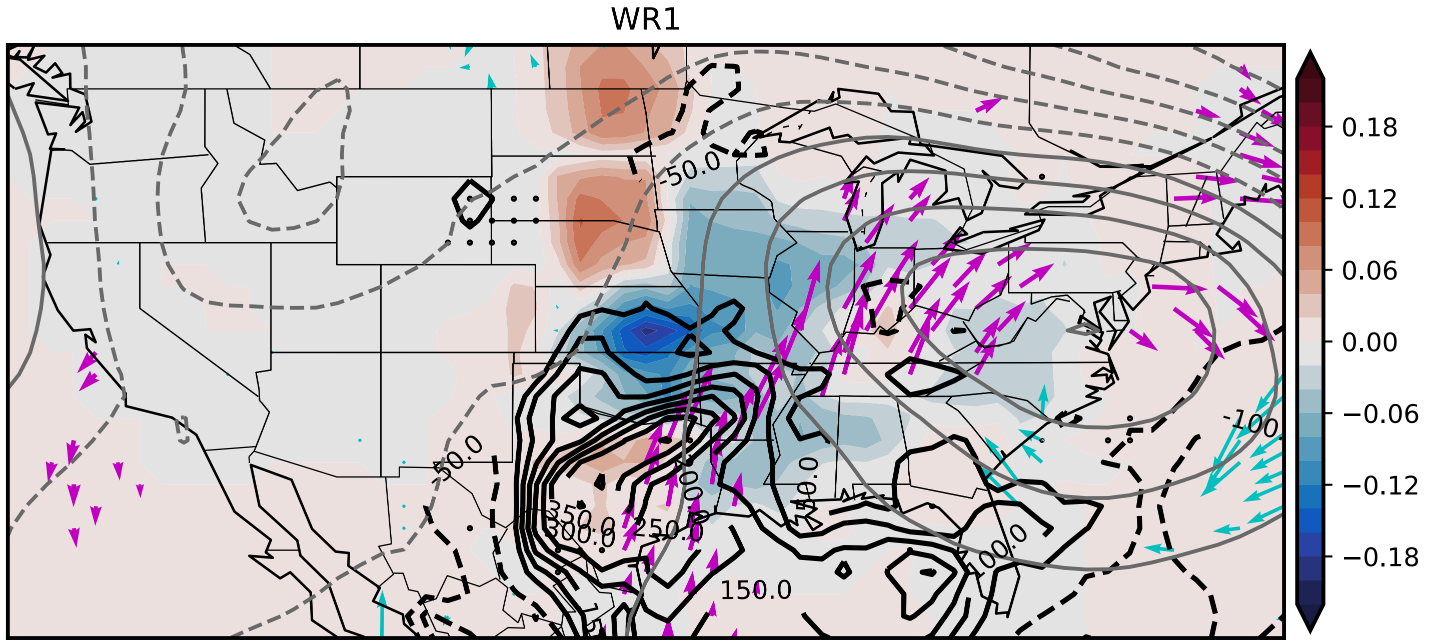
Conclusions

- 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

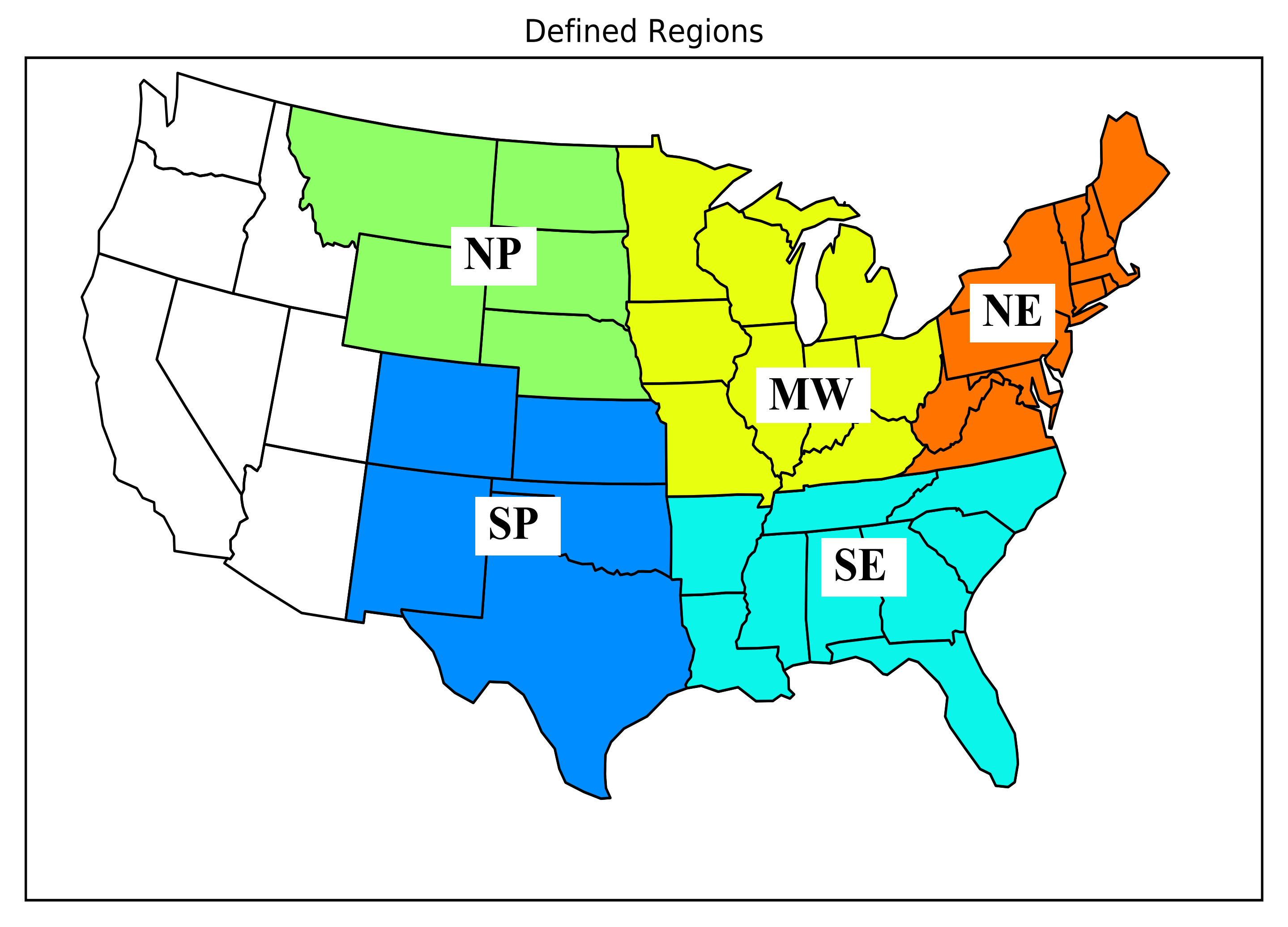
Tornado Frequency Anomalies (Shading)
CAPE Anomalies (Contours)
10-m to 900-hPa Wind Shear (vectors)

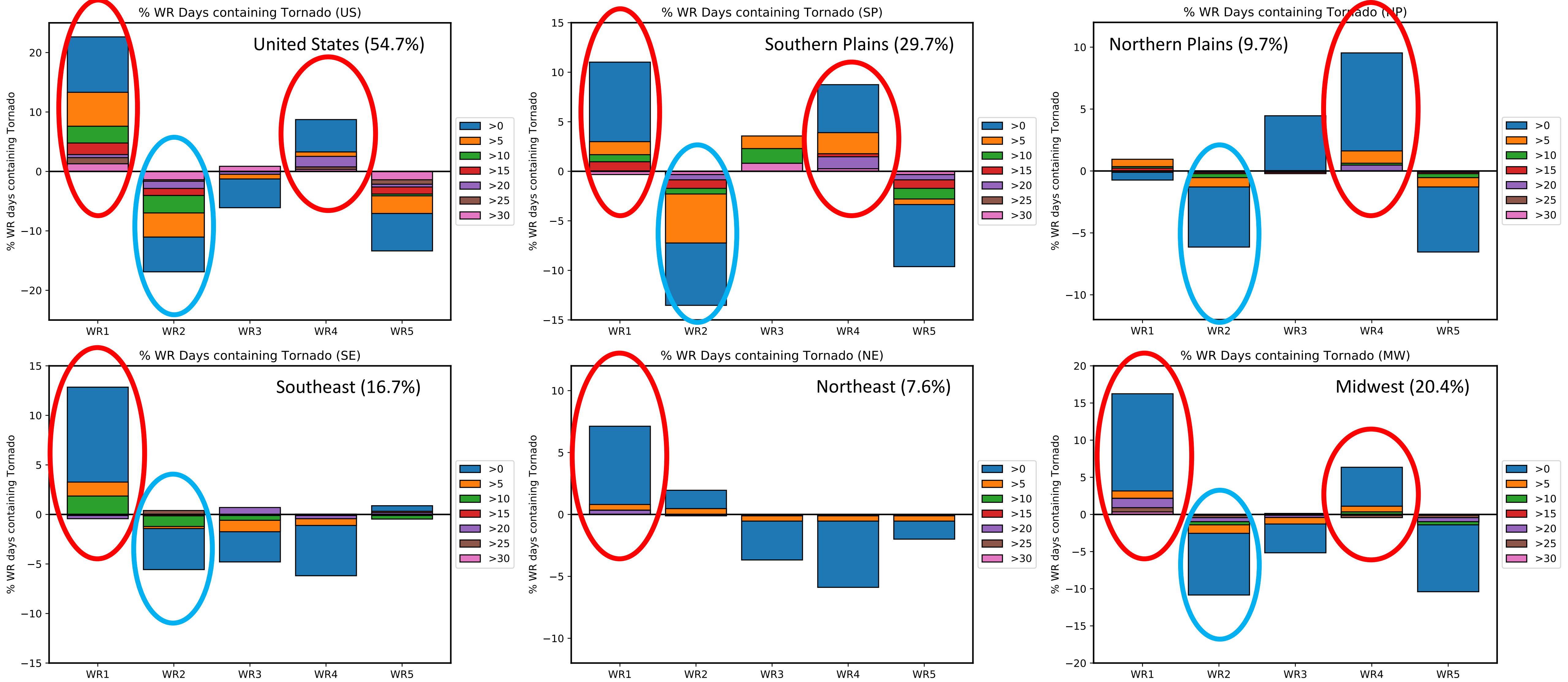


Events persisting 3 days or longer



Non-persisting events


Defined Regions
NP
NE
MW
SP
SE



% of WR days containing a tornado relative to climatology

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