*Skillful Subseasonal Forecasts of Weekly Tornado and Hail Activity using the Madden-Julian Oscillation**

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MAPP Modeling, Analysis, Predictions, and Projections

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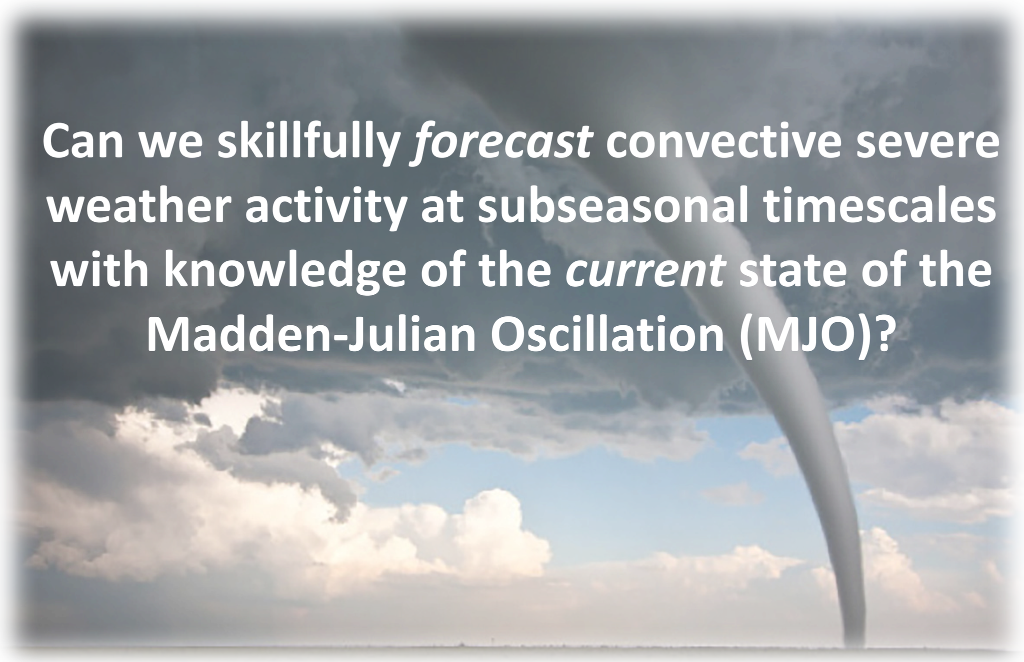
1. Motivation

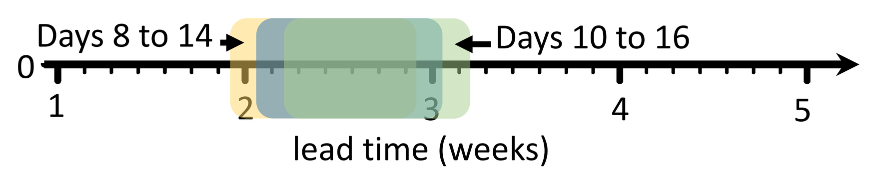
Annually, in the United States:

- Tornadoes kill ~80 people and injure ~1500 more.
- Hail storms cause ~one billion dollars in damage to property and crops.
- Accurate subseasonal forecasts of tornado and hail activity with lead times of 2-5 weeks would increase public awareness and benefit stakeholders, emergency managers, and insurers.

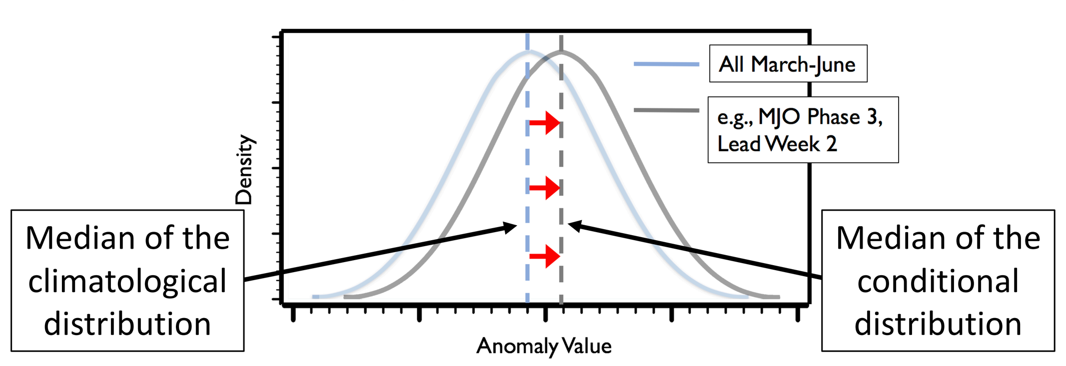


2. Data & Methods

- Tornado and hail reports from NCEP/SPC's storm reports database
  - Only EF1+ tornado reports considered
  - Only hail reports of greater than 1" diameter considered
- Tornado and hail events defined as at least one tornado or hail report occurring in a given 1.5° × 1.5° grid box in a given day.
- Two principal 7.5° × 7.5° regions studied – The Plains and The Southeast
- Environmental convective severe weather parameters of surface-based convective available potential energy (CAPE), storm relative helicity (SRH), and CAPE x SRH^2 (CSRH2) derived from ERA-Interim (1979-2015)
- Consecutive, overlapping, weekly composites and forecasts made as a function of MJO phase (OMI) and lead time:



- Empirical prediction model based on Mundhenk et al. (2018)
  - Use the current state of the MJO as a predictor
- Predict above or below normal activity by comparing the median of the conditional, MJO-phase-versus-lead-time-based distribution to the March-June climatological distribution
- Cross-validate using typical, leave-one-year-out methodology
  - Verify with the Heidke Skill Score



3. Climatology of Tornado and Hail Events

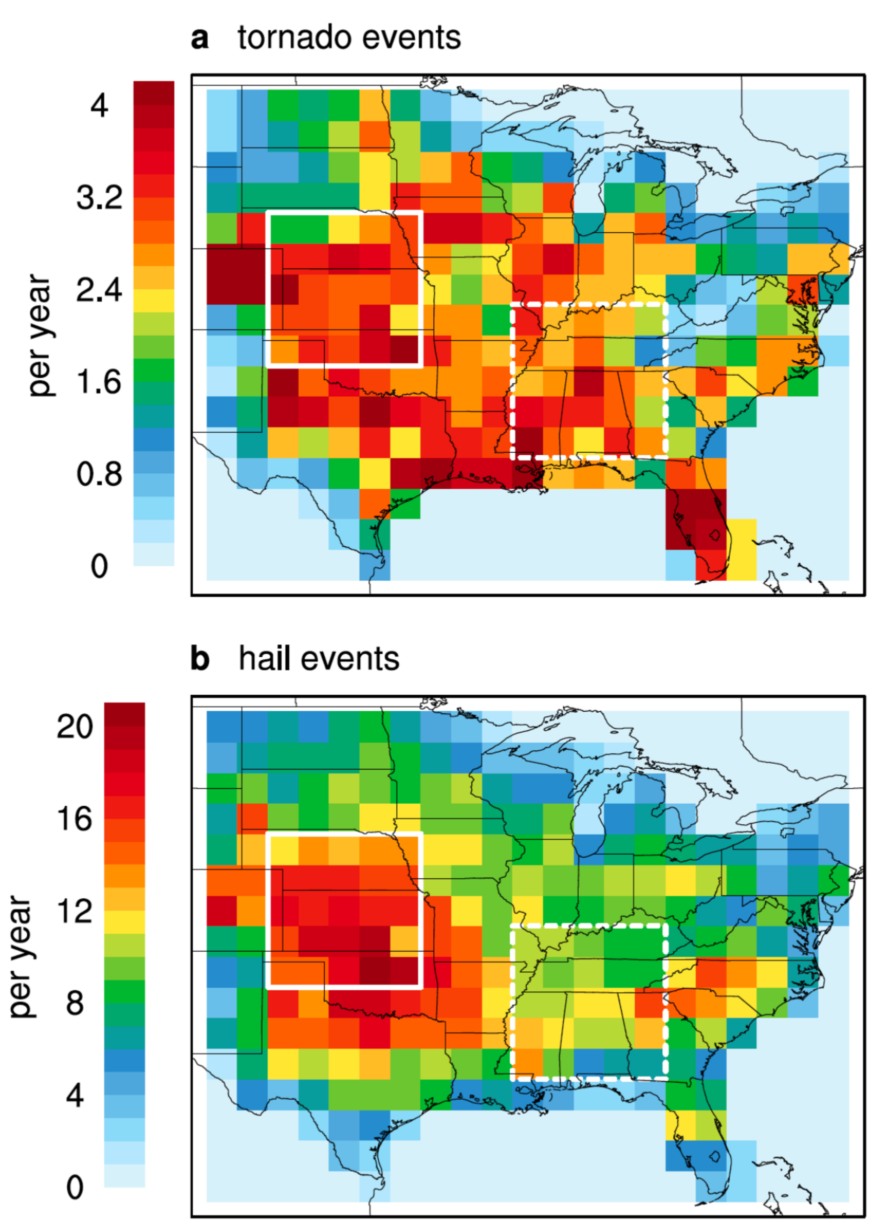


Fig. 1. The climatological number of (**a**) tornado events and (**b**) hail events per year are shown, averaged over the years 1979–2015 for each 1.5° × 1.5° grid box. The Plains and the Southeast are delimited by solid white and dashed white lines, respectively.

- **Tornadoes are common in the Plains and Southeast, while hail is more common in the Plains.**

4. Seasonal Cycles of Tornado Events, Hail Events, CAPE, SRH, and CSRH2

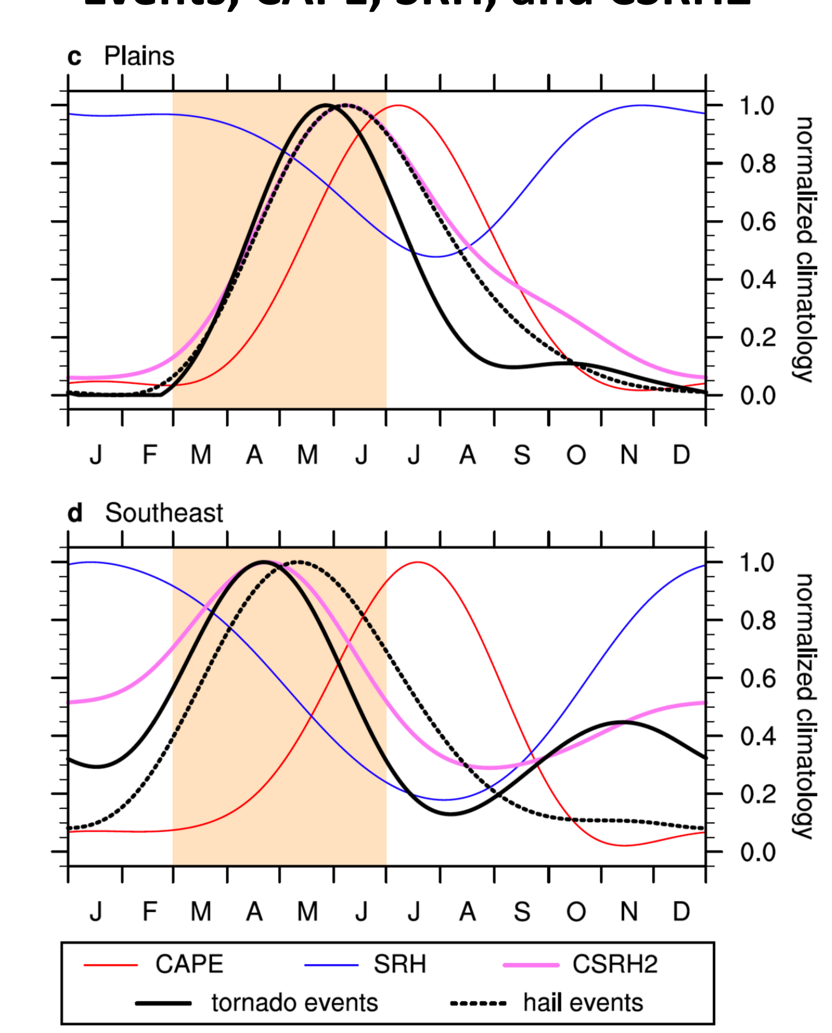


Fig. 2. Smoothed seasonal cycles of CAPE, SRH, CSRH2, tornado events, and hail events, computed over the (**c**) Plains and (**d**) Southeast. The season of interest, March-June, is shaded in light brown. The seasonal cycle for each variable has been normalized by its respective annual maximum.

- **CSRH2 serves as a better proxy for tornado and hail events than either CAPE or SRH alone.**

5. MJO Phase versus Lead Time Composites of Severe Weather Variables

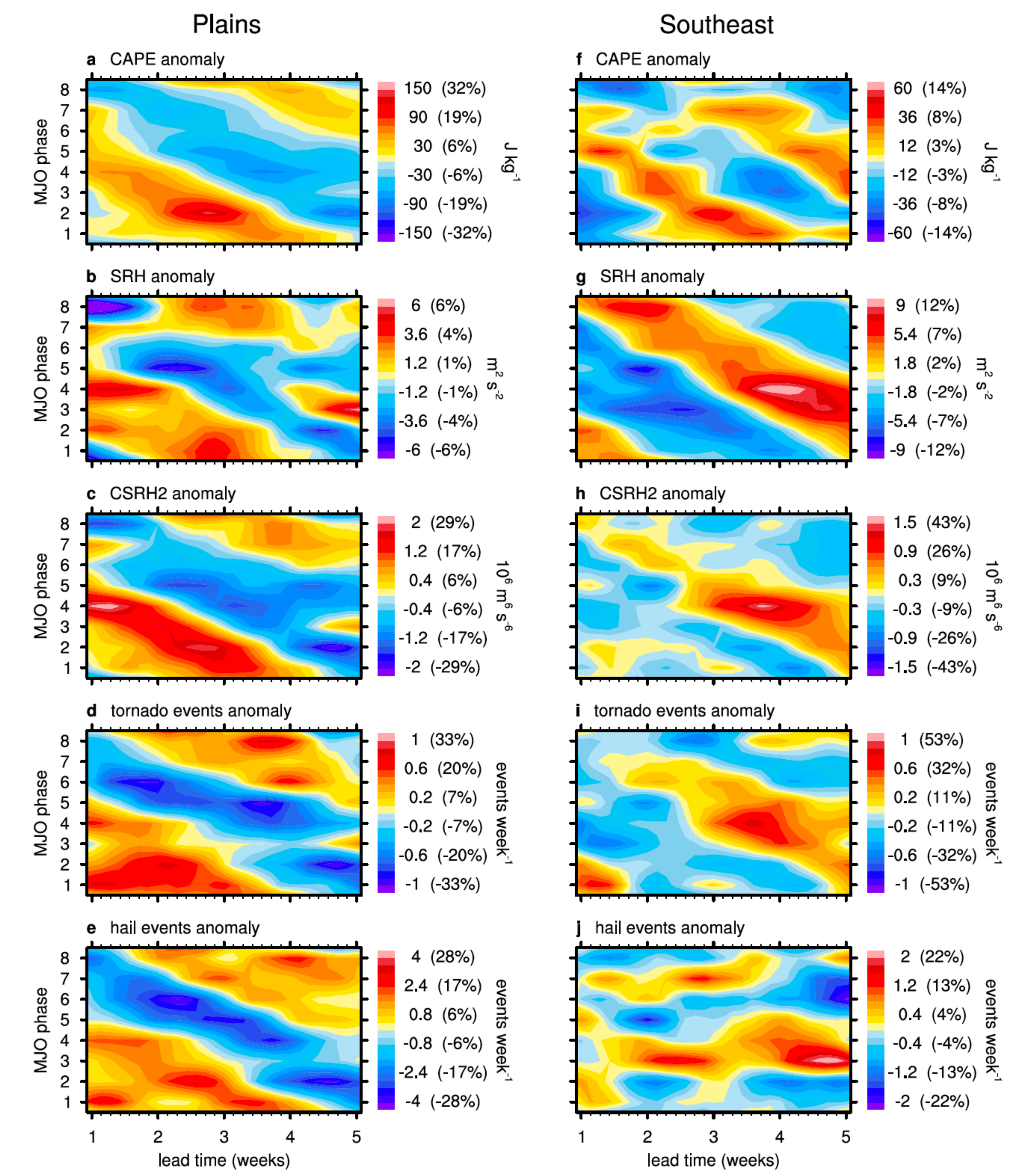


Fig. 3. Weekly composites of anomalous CAPE, SRH, CSRH2, tornado events, and hail events for the Plains and Southeast are plotted. For example, the maximum in SRH in (**g**) at a lead time of 4 weeks following phase 4 of the MJO represents the weekly averaged value of anomalous SRH for lead times spanning 22–28 days. Percentages indicate a given anomaly's deviation from its March-July climatological value.

- **CAPE, SRH, and CSRH2 have signals that propagate through MJO phases deep into subseasonal lead times.**
- **Tornado and hail events also distinctly propagate, especially in the Plains.**

6. Heidke Skill Scores of the Empirical Prediction Model

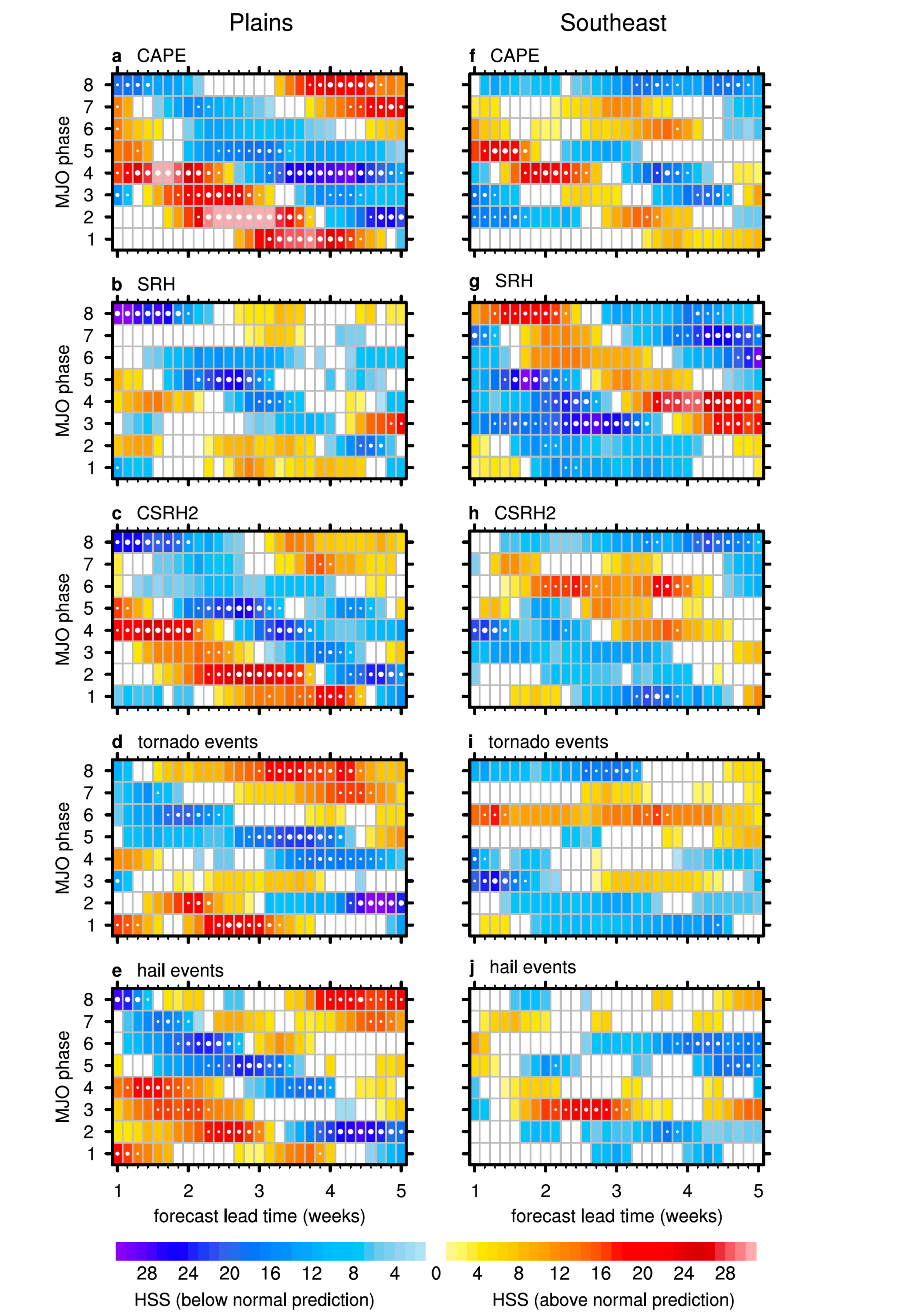


Fig. 4. Heidke skill scores of the empirical prediction model are shown for CAPE, SRH, CSRH2, tornado events, and hail events for the Plains and Southeast. Regions shaded in color have positive skill scores; regions shaded in white have negative skill scores. Warm and cool colors indicate predictions of above and below normal activity, respectively. Statistical significance is conveyed by small, medium, and large white dots for predictions that are more skillful than 80%, 90%, and 95%, respectively, of 1000 random forecast samples generated by a bootstrapping technique that accounts for autocorrelation.

- **"Forecasts of opportunity" with significant skill for CAPE, SRH, and CSRH2 extend deep into subseasonal lead times.**
- **Tornado and hail forecasts also have significant skill at subseasonal lead times in the Plains.**

7. Average Heidke Skill Scores for Overlapping 7.5° × 7.5° Regions

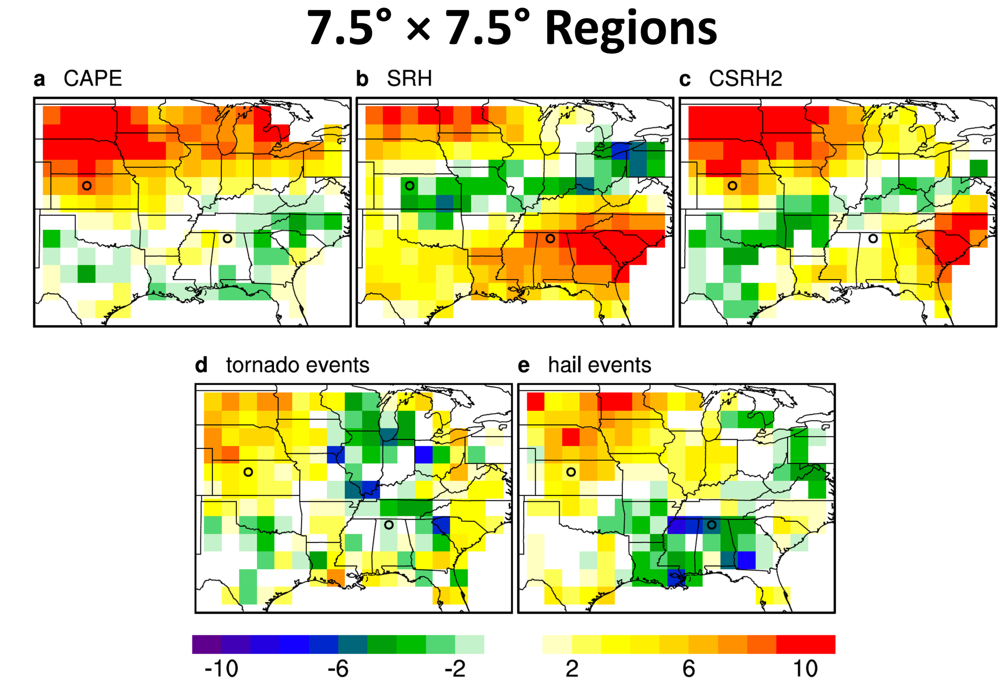


Fig. 5. Heidke skill scores that are averaged across 8 MJO phases and 29 lead times for the empirical prediction of CAPE, SRH, CSRH2, tornado events, and hail events are shown. The open black circles represent the average skill scores for the Plains and the Southeast, as derived from Figure 4. The remaining values represent the averages for each overlapping 7.5° × 7.5° region, centered every 1.5° in longitude and every 1.5° in latitude.

- **Regions in the Plains exhibit higher average skill scores for forecasts of tornado and hail events than elsewhere.**

8. Conclusion & Discussion

- ***Using only the current state of the MJO as a predictor, skillful weekly "forecasts of opportunity" exist for convective severe weather parameters and actual tornado and hail events themselves out to subseasonal lead times of 5 weeks.***
- **Possible ways to improve the empirical model include using additional predictors, expanding to three-classes, and hybridizing with dynamical model predictions of the MJO.**

9. References and Acknowledgements

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