FORECASTERS' FORUM

The Challenge of Forecasting Significant Tornadoes from June to October Using Convective Parameters

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ABSTRACT

This study is an application of the Statistical Severe Convective Risk Assessment Model (SSCRAM), which objectively assesses conditional severe thunderstorm probabilities based on archived hourly mesoscale data across the United States collected from 2006 to 2014. In the present study, SSCRAM is used to assess the utility of severe thunderstorm parameters commonly employed by forecasters in anticipating thunderstorms that produce significant tornadoes (i.e., causing F2/EF2 or greater damage) from June through October. The utility during June–October is compared to that during other months. Previous studies have identified some aspects of the summertime challenge in severe storm forecasting, and this study provides an in-depth quantification of the within-year variability of severe storms predictability. Conditional probabilities of significant tornadoes downstream of lightning occurrence using common parameter values, such as the effective-layer significant tornado parameter, convective available potential energy, and vertical shear, are found to substantially decrease during the months of June–October compared to other months. Furthermore, conditional probabilities of significant tornadoes during June–October associated with these parameters are nearly invariable regardless of value, highlighting the challenge of using objective environmental data to attempt to forecast significant tornadoes from June through October.

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1. Introduction

Attempts to improve tornado forecasting extend throughout a large part of the twentieth century to the present day owing to the high-impact nature of such phenomena. An awareness of the meteorological environment with respect to assessing severe thunderstorm potential is a fundamental component of forecasting tornadoes. In fact, the notion of assessing the meteorological environment in proximity to a tornadic storm can be traced to the 1960s and 1970s (e.g., Darkow 1968, 1969) through the use of environmental soundings. The approach to evaluating severe thunderstorm potential has evolved to anticipating the potential for mutual spatiotemporal overlap of kinematic and thermodynamic necessary conditions (e.g., Doswell 1987; Johns and Doswell 1992). The intra-annual variability of tornado potential associated with kinematic and thermodynamic parameters to assess these necessary conditions is the focus of this work.

Through the early years of research regarding the environments of severe storms including tornadoes, tornado-favoring environments are characterized by relatively larger magnitudes of buoyancy [vertically integrated to yield convective available potential energy (CAPE)] and vertical shear (e.g., Rasmussen and Wilhelmson 1983), in the most general terms. In recent years, a multitude of individual and composite parameters has been developed and tested to further categorize and discriminate among severe weather environments; these parameters are used to evaluate the ingredients relevant for severe storm forecasting. Each is a unique, statistically derived combination of parameters that can be determined from soundings based upon the phenomenon that it attempts to identify and/or forecast. For example, for deep, moist convection, Craven and Brooks (2004) evaluated the forecast utility of numerous parameters in anticipating the potential presence and severity of thunderstorms. With respect to environments supporting tornadic storms, the energy–helicity index (EHI; Hart and Korotky 1991) is an example of a parameter used to diagnose tornado potential. Even more

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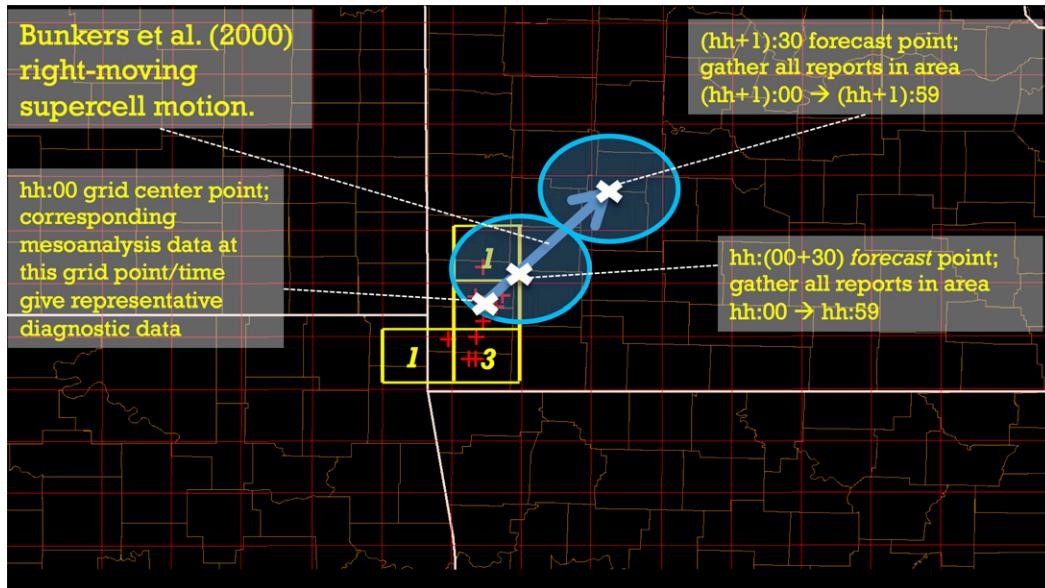E-mail: john.hart@noaa.gov

FIG. 1. Schematic that demonstrates the process of ascertaining downstream severe storm reports from each lightning-associated grid box. This figure illustrates two different search zones centered on two respective points extrapolated forward in space from the lightning-associated grid center point, based upon the Bunkers et al.'s (2000) right-moving supercell motion technique. Search circles centered along the projected storm path extend outward to 40 km. This represents a cumulative total of 2 h of severe storm report collection forward in time from the lightning-associated grid box. Severe reports in each search circle are restricted to those occurring within 30 min of the time corresponding to each respective forward-extrapolated point. [Reproduced from Hart and Cohen (2016).]

recently, Thompson et al. (2012) demonstrated the utility of the effective-layer significant tornado parameter (STP) in identifying environments that support significant tornadoes (i.e., producing F2/EF2 damage).

Many of the aforementioned parameters, particularly ones involving forms of CAPE, vertical shear, and combinations of these, have become well instilled within the vernacular of the modern-day severe thunderstorm forecaster. Their values are associated with often-cited numerical benchmarks that are used as guidance in characterizing the propensity of particular environments to support severe thunderstorms. Given the diagnostic nature of these variables, their use as forecasting proxies is questionable, at best. Specifically, Doswell and Schultz (2006) deemed diagnostic parameters describing initial atmospheric conditions as having limited predictability of the future state of the atmosphere. However, they did identify the possibility of using diagnostic data to explicitly express probabilistic information in severe thunderstorm forecasting, in which the combination of occurrences of events and nonevents (null cases) is used to derive the probability of event occurrence. This notion is the foundation of a companion paper, in which Hart and Cohen (2016) developed the Statistical Severe Convective Risk Assessment Model (SSCRAM). This system couples 9 yr of

lightning data to severe thunderstorm reports to evaluate 1) the conditional probability of severe thunderstorm reports occurring downstream of observed lightning occurrences and 2) the relative frequency of severe thunderstorm reports occurring within various ranges of numerous parameters.

SSCRAM systematically addresses the predictability of diagnostic parameters as motivated by Doswell and Schultz (2006), and Hart and Cohen (2016) provided examples of the relationship between a subset of five thermodynamic, kinematic, and composite variables in forecasting individual severe storm hazards (wind, hail, and tornadoes). Relevant to the present study, they provided a specific focus on parameters associated with tornado forecasting, and identified conditional tornado probabilities given lightning occurrence. These probabilities show that effective-layer STP and effective storm-relative helicity provide the greatest utility in forecasting significant tornadoes (i.e., an increase in parameter values is often related to an increase in the probability of occurrence). On the other hand, individual thermodynamic parameters such as lifting condensation level (LCL) height and instability quantities yield substantially weaker forecast utility.

With SSCRAM having a large sample size, being built upon nearly 3.8 million data points, it affords us the opportunity to broaden the scope of severe storm probabilistic parameter-based guidance. This not only includes an

SSCRAM conditional probabilities of significant tornadoes by month using effective-layer significant tornado parameter for November–May
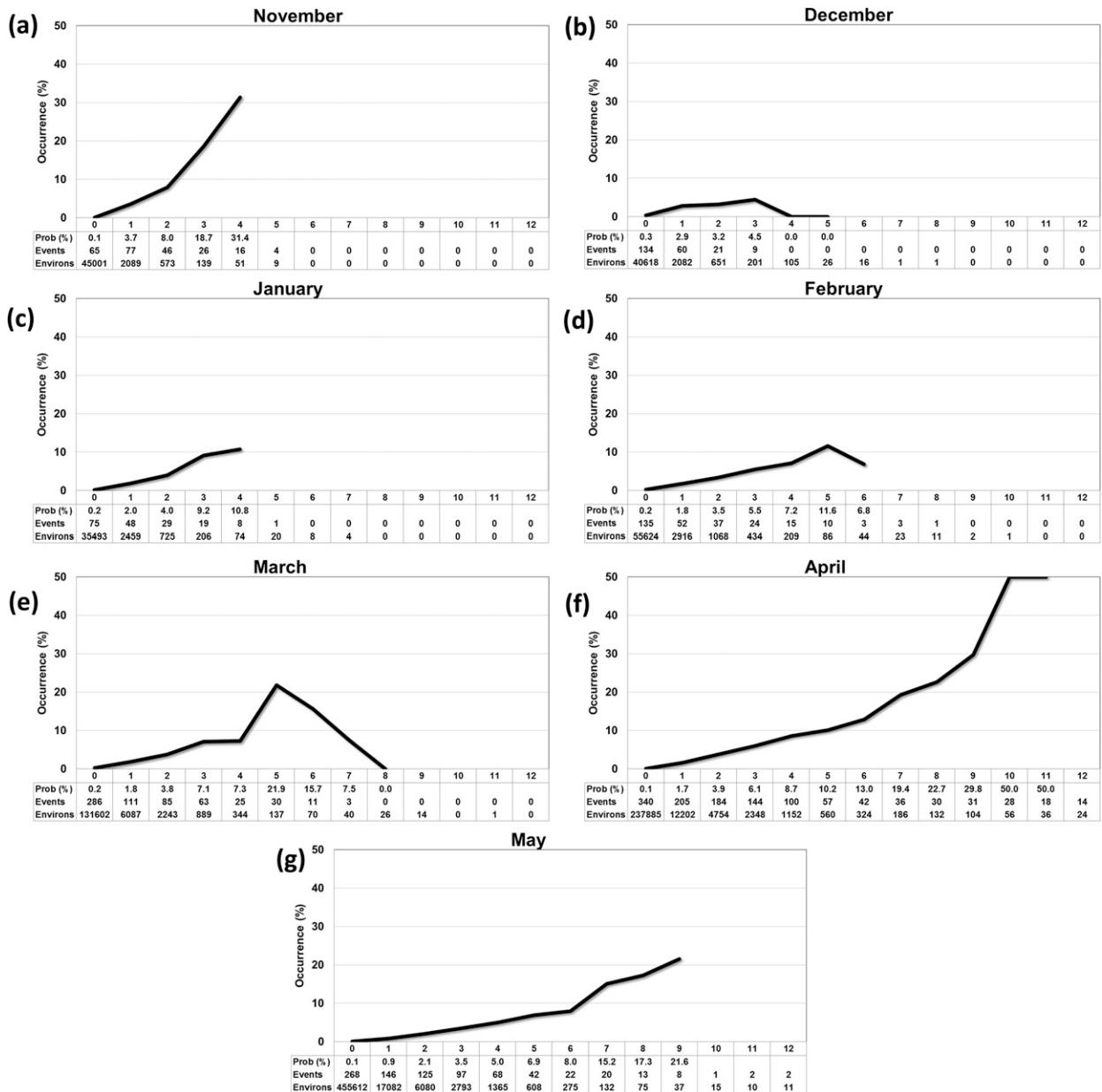

FIG. 2. Conditional probabilities of significant tornadoes based on the effective-layer STP by month during N–M, with each month of the year corresponding to a panel labeled by the month's name. Conditional probabilities (Prob) are derived by dividing the number of grid boxes associated with reported downstream significant tornadoes (Events) by the number of grid boxes merely meeting constraints of lightning occurrence and STP range (Environs). Labels immediately beneath the x axis provide the lower bounds of STP ranges and corresponding Prob, Events, and Environs values. The Prob values are not provided for parameter-bin ranges with Environs values < 25.

investigation of the probabilistic utility of various variables at large, but also includes an investigation of their *seasonal* utility. The stratification of the SSCRAM dataset based on tornado intensity *and* season builds upon work on tornado-related conditional probability evaluation developed by Togstad et al. (2011) and Smith et al. (2015)

by adding a seasonal component. The purpose of the present study is to identify differences in the forecast utility associated with parameters describing tornado environments throughout the year.

While the physical laws governing severe storm development are invariable, the forecast utility of parameters

SSCRAM conditional probabilities of significant tornadoes by month using effective-layer significant tornado parameter for June-October
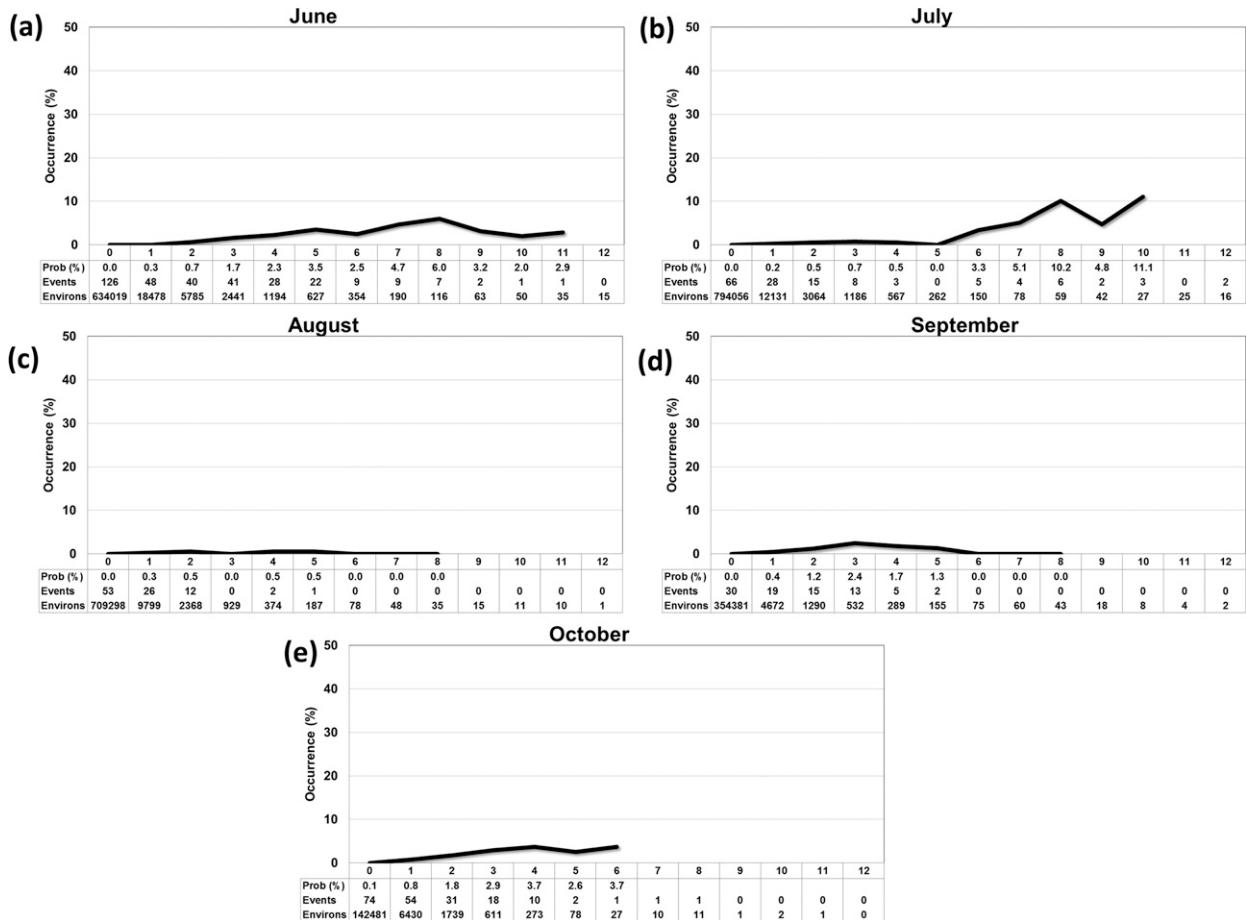

FIG. 3. As in Fig. 2, but for the months of J–O.

that only partially represent these laws may certainly be variable, especially considering the wide array of convective modes that either support or inhibit tornadogenesis (e.g., Smith et al. 2012; Thompson et al. 2012; Edwards et al. 2012). More specifically, the relevance of a given parameter during one season in terms of anticipating downstream severe thunderstorm occurrence of observed lightning may not be the same in another season. Previous research has indeed highlighted the complexities of warm-season convective regimes. For example, Jankov and Gallus (2004) identified challenges in forecasting during weak-forcing-for-ascent convective regimes, which more frequently typify warm-season patterns, from a numerical modeling perspective. These findings highlight previous research that identifies aspects of warm-season severe storms forecasting that could prove to be challenging, particularly from a tornado-forecasting aspect.

Interseasonal variability for certain parameters in forecasting tornado potential may render all-season

parameter-based severe storm probabilities less useful for individual seasons, along with other parameter-derived output for conditional tornado probabilities as identified by previous work, including Hart and Cohen (2016) and Togstad et al. (2011). Quantifying this variability in predictability for significant tornadoes using the SSCRAM system is the focus of the present work.

2. Data, methods, and analysis

SSCRAM, as described by Hart and Cohen (2016), is used as the basis for evaluating probabilities of severe storm occurrence given a lightning strike and mesoscale environmental information in proximity to the lightning. These probabilities correspond to severe storm occurrence downstream of the initial-hour grid box corresponding to the lightning strike(s), as illustrated in Fig. 1, with forward motion estimated from Bunkers et al.'s (2000) right-moving supercell motion technique. As

Significant Tornado Parameter

(Nov-May) vs. (Jun-Oct) Comparison

EF2-EF5 Tornado

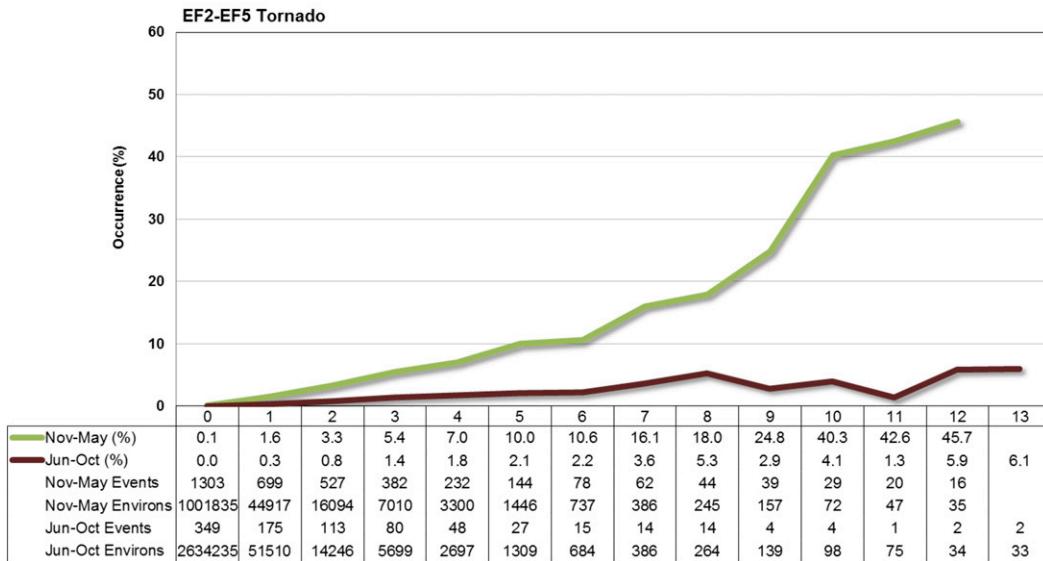|	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Nov-May (%)	0.1	1.6	3.3	5.4	7.0	10.0	10.6	16.1	18.0	24.8	40.3	42.6	45.7	
Jun-Oct (%)	0.0	0.3	0.8	1.4	1.8	2.1	2.2	3.6	5.3	2.9	4.1	1.3	5.9	6.1
Nov-May Events	1303	699	527	382	232	144	78	62	44	39	29	20	16	
Nov-May Environs	1001835	44917	16094	7010	3300	1446	737	386	245	157	72	47	35	
Jun-Oct Events	349	175	113	80	48	27	15	14	14	4	4	1	2	2
Jun-Oct Environs	2634235	51510	14246	5699	2697	1309	684	386	264	139	98	75	34	33

FIG. 4. Conditional probabilities of significant tornadoes based on STP grouped from N–M (dark green) and overlaid with those grouped from J–O (dark brown). Corresponding values of conditional probabilities are listed beneath the *x* axis, along with the number of grid boxes associated with the reported downstream significant tornadoes (Events) and the number of grid boxes merely meeting constraints (Environs) of lightning occurrence and STP range. Labels immediately beneath the *x* axis provide the lower bounds of STP ranges. For each parameter-range bin, the conditional probability is equivalent to the Events value divided by the Environs value and is not computed for parameter-bin ranges with Environs values < 25.
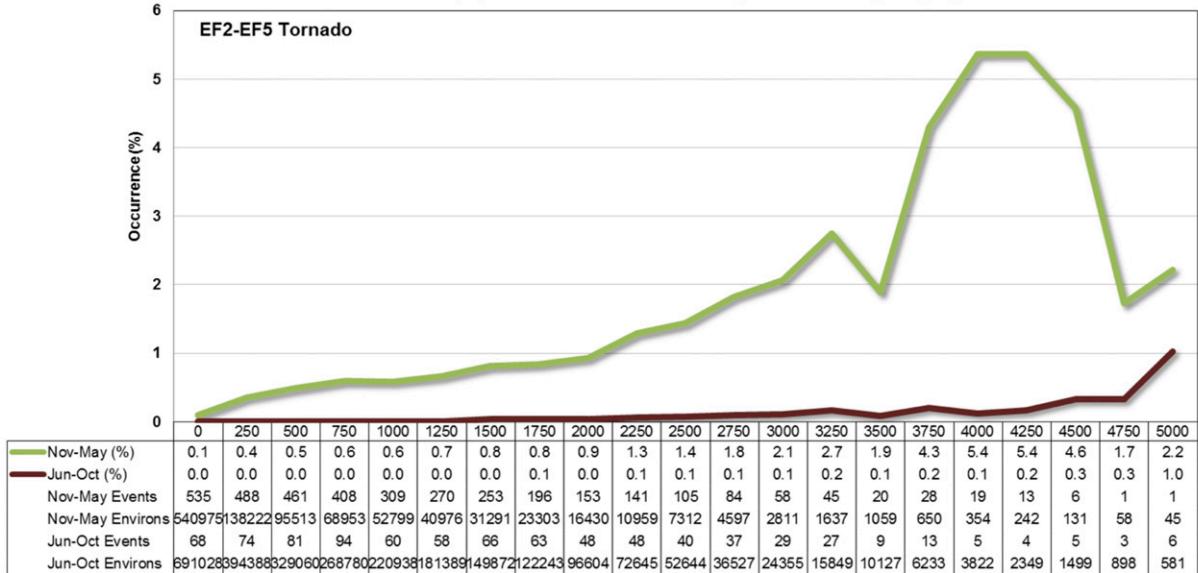
described by Hart and Cohen (2016) regarding the development of the SSCRAM system, the Bunkers et al. (2000) technique seems to be an appropriate method for estimating storm motion for the purposes of this study when compared to other storm motion estimates, including the modified Bunkers et al. (2014) technique, the 30R75 method [i.e., estimate of storm motion direction to be to the right of the mean wind by 30°, with storm motion magnitude being 75% of the mean wind speed per Maddox (1976)], and the pressure-weighted mean wind. SSCRAM provides both the conditional probability of severe-event occurrence within particular ranges of parameter values, and the relative frequency of severe-event occurrences for various ranges of a parameter-value spectrum. The present study exhibits these concepts in subsequently described figures.

Hart and Cohen (2016) demonstrated the overall utility of STP in assessing tornado probabilities downstream of lightning-producing convection, with notably increasing significant tornado probability as STP increases. The STP combines effective storm-relative helicity (Thompson et al. 2007), the LCL of the lowest-100-mb mixed-layer parcel, effective bulk shear (Thompson et al. 2007), mixed-layer convective available potential energy (MLCAPE), and mixed-layer convective inhibition (MLCIN). Examination of the conditional probabilities of significant tornado occurrence reveals the variable utility of STP from month to month (Figs. 2 and 3). Specifically, there is a much stronger practical relationship between STP and significant tornado occurrences in April, compared to September when conditional probabilities vary little across STP values. This suggests less utility of STP in evaluating downstream significant tornado potential in September compared to April.

For the purposes of generalizing our results, we analyze temporally continuous periods of similar-characteristic significant tornado predictability. There appear to be two distinct periods during which the characteristics of the probability distributions in predicting significant tornadoes using STP are similar (Figs. 2 and 3). Specifically, months from November through May (N–M) are associated with general increases in conditional probabilities with increasing STP values. One exception is December, though the sample sizes of environments in December are relatively small, permitting its inclusion in the continuous N–M period. Other exceptions include small perturbations within the spectrum of STP values whose physical explanations are outside the scope of this work. Meanwhile, the months of June–October (J–O) are associated with little variability across STP values for these conditional probabilities. Subsequently, the

(a) 100mb Mixed-Layer CAPE (J kg⁻¹)

EF2-EF5 Tornado

	0	250	500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000	3250	3500	3750	4000	4250	4500	4750	5000
Nov–May (%)	0.1	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.3	1.4	1.8	2.1	2.7	1.9	4.3	5.4	5.4	4.6	1.7	2.2
Jun–Oct (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.3	0.3	1.0
Nov–May Events	535	488	461	408	309	270	253	196	153	141	105	84	58	45	20	28	19	13	6	1	1
Nov–May Environs	540975	138222	95513	68953	52799	40976	31291	23303	16430	10959	7312	4597	2811	1637	1059	650	354	242	131	58	45
Jun–Oct Events	68	74	81	94	60	58	66	63	48	48	40	37	29	27	9	13	5	4	5	3	6
Jun–Oct Environs	691028	394388	329060	268780	220938	181389	149872	122243	96604	72645	52644	36527	24355	15849	10127	6233	3822	2349	1499	898	581

(b) 100mb Mixed-Layer CIN (J kg⁻¹)

EF2-EF5 Tornado

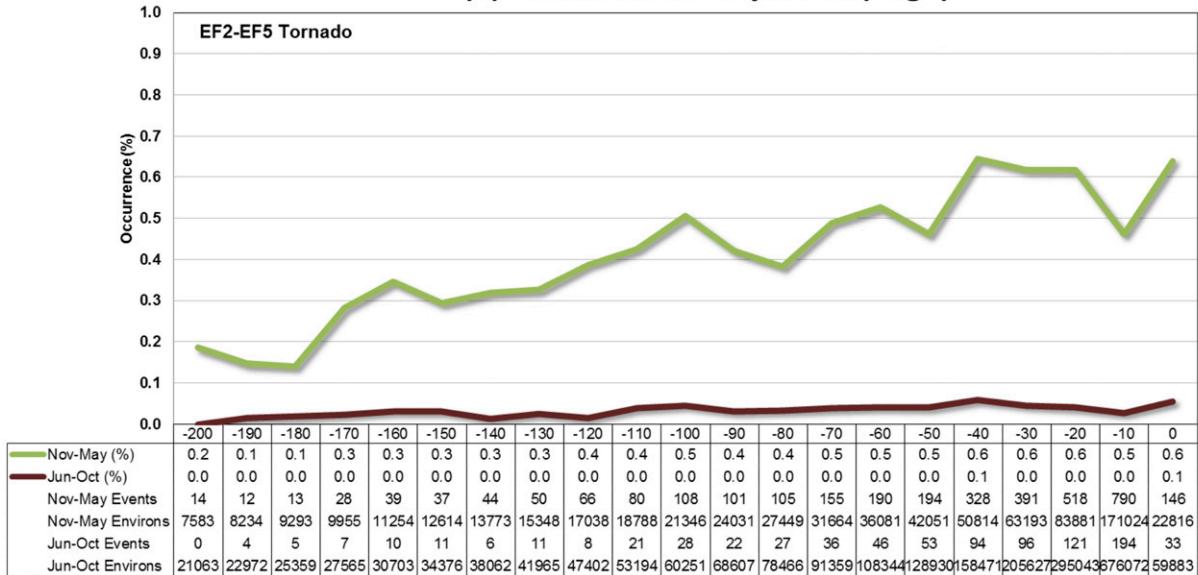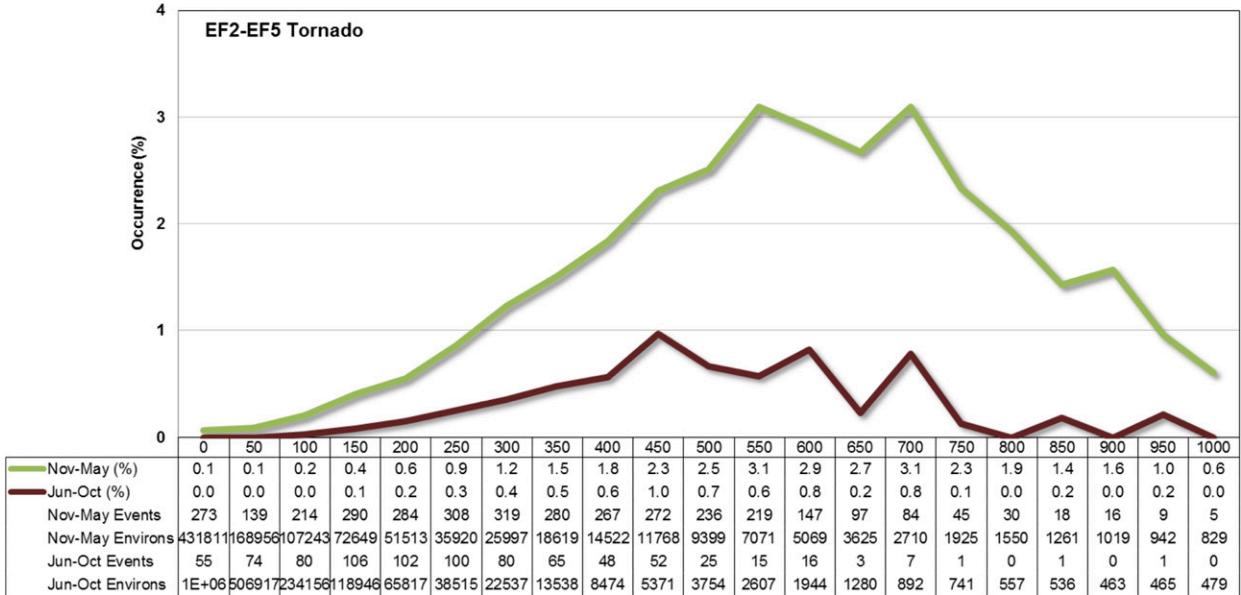|	-200	-190	-180	-170	-160	-150	-140	-130	-120	-110	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0
Nov–May (%)	0.2	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.6
Jun–Oct (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Nov–May Events	14	12	13	28	39	37	44	50	66	80	108	101	105	155	190	194	328	391	518	790	146
Nov–May Environs	7583	8234	9293	9955	11254	12614	13773	15348	17038	18788	21346	24031	27449	31664	36081	42051	50814	63193	83881	171024	22816
Jun–Oct Events	0	4	5	7	10	11	6	11	8	21	28	22	27	36	46	53	94	96	121	194	33
Jun–Oct Environs	21063	22972	25359	27565	30703	34376	38062	41965	47402	53194	60251	68607	78466	91359	108344	128930	158471	205627	295043	676072	59883

FIG. 5. As in Fig. 4, but for (a) MLCAPE and (b) MLCIN.

SSCRAM system is used to study two separate, temporally continuous periods of significant tornado predictability using STP: higher predictability in N–M that includes the cool season and lower predictability in J–O that includes the warm season. In fact, J–O significant tornado conditional probabilities fall substantially, by a factor of generally around 5–10, from the corresponding N–M probabilities, and offer little to no variability among the ranges of STP values, as shown in Fig. 4. This approach suggests STP has limited forecast utility during J–O.

A major challenge exists in explaining the decrease in the utility of STP in forecasting significant tornadoes during J–O compared to N–M, as this notion is counterintuitive. This parameter lies at the forefront of diagnostic methods in assessing significant tornado potential, and the aforementioned findings suggest that significant tornado predictability falls during the transition from N–M to J–O. It is possible that this could be related to the greater predictability of more strongly forced convective events (e.g., Jankov and Gallus 2004) that are more characteristic of N–M than J–O. Furthermore, some of the N–M to J–O

(a) Effective Helicity (m² s⁻²)

EF2–EF5 Tornado

	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
Nov–May (%)	0.1	0.1	0.2	0.4	0.6	0.9	1.2	1.5	1.8	2.3	2.5	3.1	2.9	2.7	3.1	2.3	1.9	1.4	1.6	1.0	0.6
Jun–Oct (%)	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	1.0	0.7	0.6	0.8	0.2	0.8	0.1	0.0	0.2	0.0	0.2	0.0
Nov–May Events	273	139	214	290	284	308	319	280	267	272	236	219	147	97	84	45	30	18	16	9	5
Nov–May Environs	431811	168956	107243	72649	51513	35920	25997	18619	14522	11768	9399	7071	5069	3625	2710	1925	1550	1261	1019	942	829
Jun–Oct Events	55	74	80	106	102	100	80	65	48	52	25	15	16	3	7	1	0	1	0	1	0
Jun–Oct Environs	1E+06	506917	234156	118946	65817	38515	22537	13538	8474	5371	3754	2607	1944	1280	892	741	557	536	463	465	479

(b) Effective Bulk Shear (kt)

EF2–EF5 Tornado

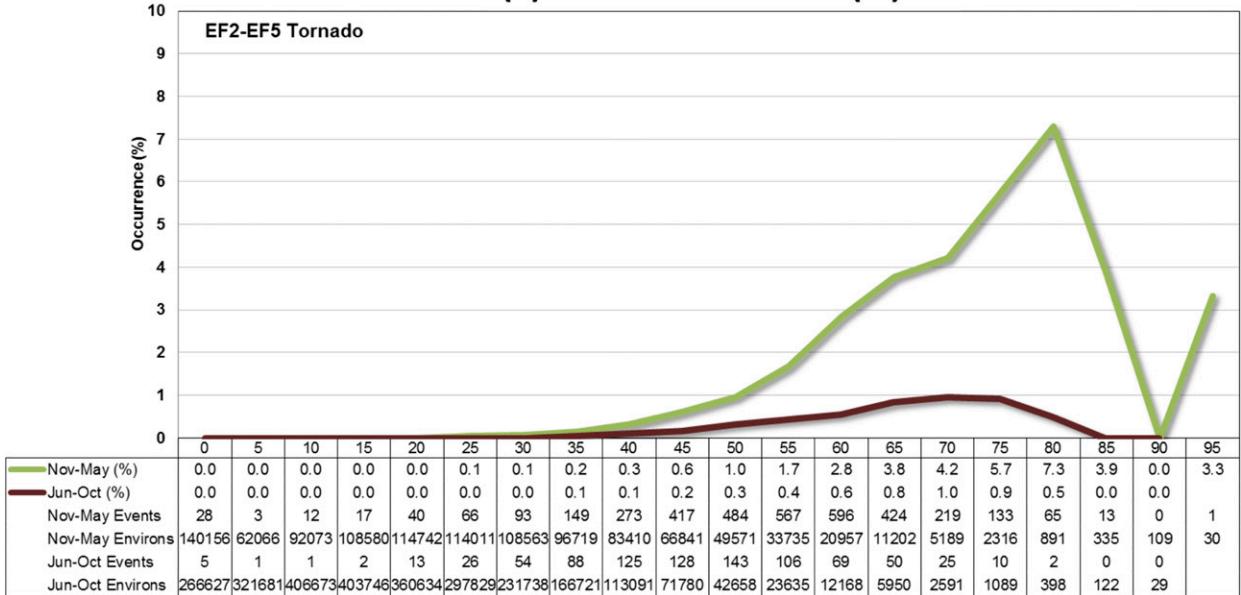|	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Nov–May (%)	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.6	1.0	1.7	2.8	3.8	4.2	5.7	7.3	3.9	0.0	3.3
Jun–Oct (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	1.0	0.9	0.5	0.0	0.0	
Nov–May Events	28	3	12	17	40	66	93	149	273	417	484	567	596	424	219	133	65	13	0	1
Nov–May Environs	140156	62066	92073	108580	114742	114011	108563	96719	83410	66841	49571	33735	20957	11202	5189	2316	891	335	109	30
Jun–Oct Events	5	1	1	2	13	26	54	88	125	128	143	106	69	50	25	10	2	0	0	
Jun–Oct Environs	266627	321681	406673	403746	360634	297829	231738	166721	113091	71780	42658	23635	12168	5950	2591	1089	398	122	29	

FIG. 6. As in Fig. 4, but for (a) effective SRH and (b) effective bulk shear.

decrease in the predictability of significant tornadoes using STP could be associated with the influence of the heterogeneities of mesoscale parameters and associated boundaries not resolved by the SSCRAM system on significant tornado potential, along with the lack of representation of advection processes influencing the downstream environment and other limitations of the SSCRAM system that Hart and Cohen (2016) address.

The reduction of forecast utility of STP from N–M to J–O is also reflected by the reduction of the predictability of significant tornadoes using individual components of the STP, as illustrated by Figs. 5 and 6. Figure 5 shows that the already limited predictability of MLCAPE in assessing significant tornado conditional probabilities is even more limited during J–O, transitioning from a weakly varying probability curve with increasing MLCAPE during N–M, to a near-flat curve with near-zero probabilities during J–O. The same general tendencies are evident for effective-layer storm-relative helicity, and effective bulk shear. While not
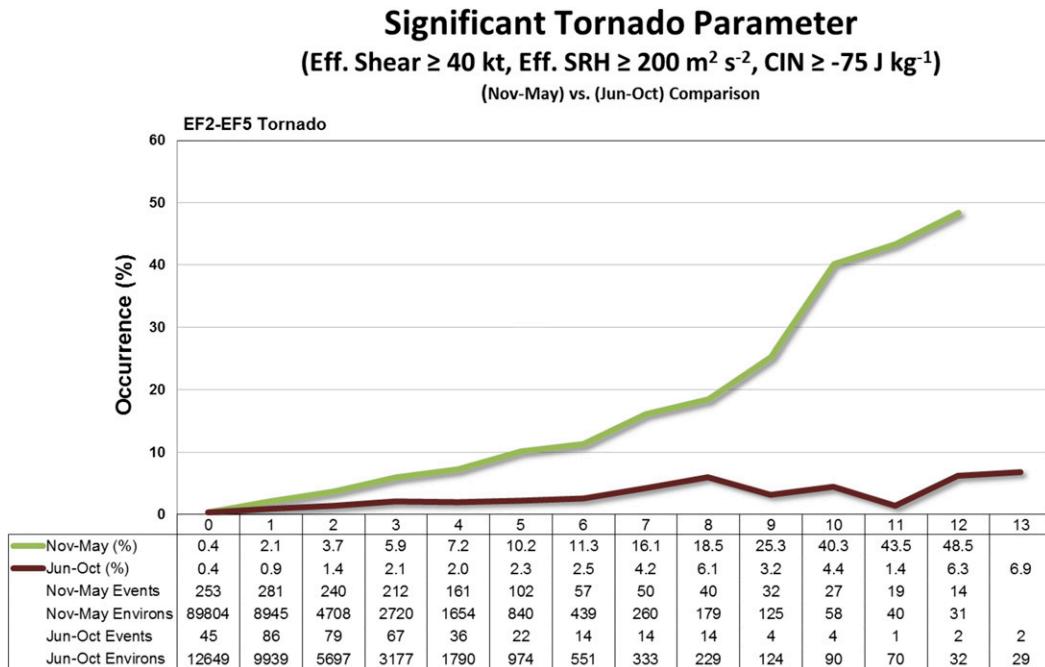
Significant Tornado Parameter

(Eff. Shear ≥ 40 kt, Eff. SRH ≥ 200 m² s⁻², CIN ≥ -75 J kg⁻¹)

(Nov-May) vs. (Jun-Oct) Comparison

	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Nov-May (%)	0.4	2.1	3.7	5.9	7.2	10.2	11.3	16.1	18.5	25.3	40.3	43.5	48.5	
Jun-Oct (%)	0.4	0.9	1.4	2.1	2.0	2.3	2.5	4.2	6.1	3.2	4.4	1.4	6.3	6.9
Nov-May Events	253	281	240	212	161	102	57	50	40	32	27	19	14	
Nov-May Environs	89804	8945	4708	2720	1654	840	439	260	179	125	58	40	31	
Jun-Oct Events	45	86	79	67	36	22	14	14	14	4	4	1	2	2
Jun-Oct Environs	12649	9939	5697	3177	1790	974	551	333	229	124	90	70	32	29

FIG. 7. As in Fig. 4, but using constraints of effective-layer SRH $\geq 200 \, \text{m}^2 \, \text{s}^{-2}$, effective bulk shear magnitude $\geq 40 \, \text{kt}$, and MLCIN $\geq -75 \, \text{J} \, \text{kg}^{-1}$.

specifically analyzed by Hart and Cohen (2016) with respect to evaluating severe thunderstorm predictability, Fig. 5 also displays MLCIN, as Davies (2004) found that lower magnitudes of MLCIN correspond to higher frequencies of tornadoes rated F1–F4. We find that any modest signal for significant tornado probability to increase with decreasing magnitude of MLCIN during N–M largely vanishes during J–O. Figure 6 highlights the decline in the predictability of significant tornadoes using the kinematic parameters of effective SRH and effective bulk shear. Thus, Figs. 5 and 6 collectively demonstrate the decrease in the forecast utility of diagnostic variables in assessing significant tornado potential from N–M to J–O. These parameters summarize basic ingredients of severe thunderstorm environments and appear to offer little predictability in J–O. Even restricting to environmental cases of strong environmental shear [storm-relative helicity of over $200 \, \text{m}^2 \, \text{s}^{-2}$, effective bulk shear over 40 kt (where $1 \, \text{kt} = 0.51 \, \text{m} \, \text{s}^{-1}$), and weak CIN], which would further condition the dataset to focus on supercell thunderstorm potential, shows that STP offers substantially less utility for prediction in J–O compared to N–M (Fig. 7).

3. Discussion and conclusions

Parameters describing the kinematic and thermodynamic mesoscale environment of severe thunderstorms have become an important part of the process of assessing the likelihood for severe thunderstorm development in a short-term forecasting mode. Forecasters have relied on certain fields, such as CAPE and vertical shear, along with composite parameters like STP, to assess this environment from a diagnostic perspective. There may be utility in extending these diagnostic variables to express prognostic information, and such an undertaking is the purpose of SSCRAM (Hart and Cohen 2016). SSCRAM attempts to accomplish the challenge offered by Doswell and Schultz (2006) to garner prognostic power from diagnostic variables in a reproducible manner.

Hart and Cohen (2016) have demonstrated that it is certainly possible to quantitatively assign probabilities to severe thunderstorm hazard occurrence downstream of observed lightning occurrence, in general. Their results combine data through all months of the year. However, J–O offers a substantially more challenging forecast problem. Figure 8 provides an illustration of this problem through an individual J–O case, in which multiple supercell thunderstorms were ongoing over an area of relatively substantial values of significant tornado parameter (over 2) across parts of the lower Great Lakes and the Ohio valley region on 13 July 2015. None of these storms produced significant tornadoes. Yet, the only significant tornado of the day was well to the west, in south-central Kansas, in an environment
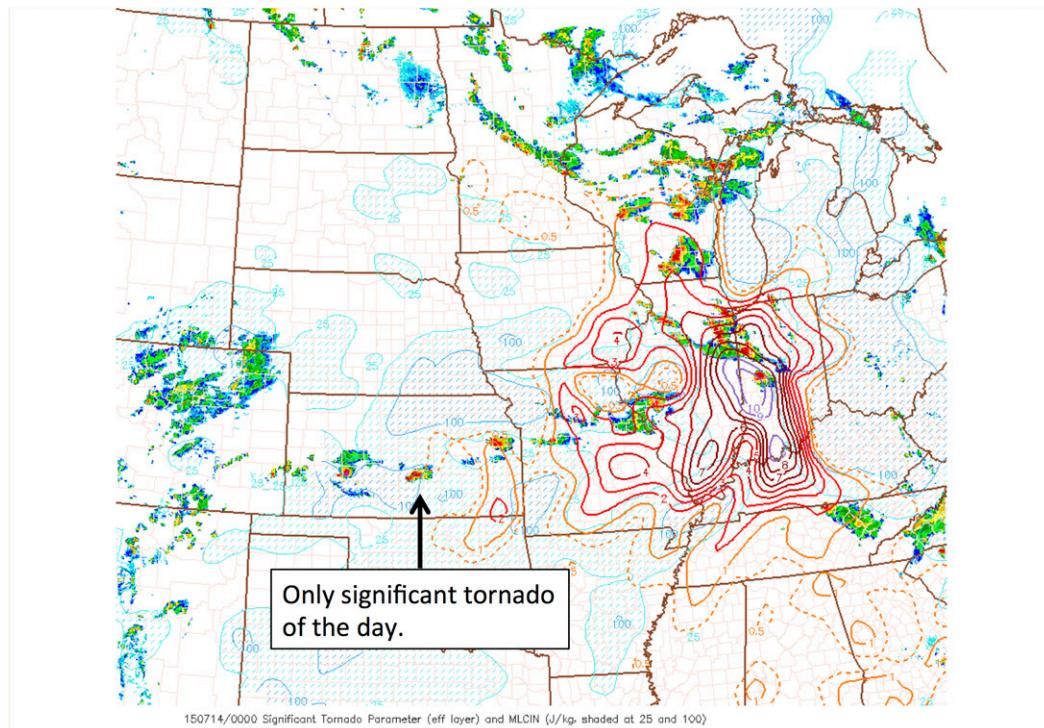
FIG. 8. Overlay of significant tornado parameters (orange, red, and purple contours), MLCIN (light blue and darker blue contours with inner hatched areas), and mosaic radar imagery corresponding to the 0000 UTC Storm Prediction Center (SPC) mesoanalysis (Bothwell et al. 2002) graphics on 14 Jul 2015. The supercell thunderstorm that produced the only significant tornado of the day is marked in south-central KS.

characterized by substantially lower values of STP. This tornado was associated with a supercell thunderstorm evolving amid a background frontal zone.

We enumerate the number of grid boxes containing CG lightning combined with a constraint of STP being at least 3. This STP threshold is intended to identify environments that are strongly favorable for significant tornadoes. We find that 13 486 (11 445) grid boxes meet these constraints in N–M (J–O), while 1063 (211) grid boxes yield downstream significant tornadoes in N–M (J–O). As such, the exceedance probability of a significant tornado when STP values are at least 3 reduces from 7.9% in N–M to 1.8% in J–O. This is a dramatic reduction by over a factor of 4. The reduced efficiency of significant tornado environments from N–M to J–O, as identified using the SSCRAM system, is consistent with the reduced predictability of this phenomenon as previously discussed.

Ultimately, the SSCRAM technique suggests that significant tornadoes are less predictable during J–O compared to N–M. There are multiple possible explanations for the disparate probabilistic distributions shown in Figs. 2–7 for N–M versus J–O. First, one possible explanation is that cloud-to-ground (CG) lightning is not a good proxy for supercells (in the same STP

environment) in J–O compared to N–M. The convective mode sample developed by Smith et al. (2012) suggests that supercells producing tornadoes or significant severe weather are less common in summer than spring, despite more numerous lightning grid hours in the summer. Likewise, the ratios of summer-to-spring grid-hour environments (within specific ranges of STP values in the presence of an observed supercell) are quite similar to the ratios of EF-scale damage class ratings for known tornadic supercells. However, the Smith et al. (2012) sample did not include supercells producing sub-significant hail or damaging winds, and it is conceivable that such supercells are more common in the summer versus the spring.

Another hypothesis is that the SSCRAM technique does not work as well during J–O owing to the possibility that the assumed storm motion procedure in SSCRAM is less applicable during this period. Yet another hypothesis is that the parameter components of STP are poor representations of significant tornado potential in J–O, when it is likely that STP lacks elements on the storm scale (e.g., surface boundary interactions) that might be important in the more isolated significant tornado events. Furthermore, the diminished predictability of significant tornadoes using STP during J–O may be

related to limitations of the SSCRAM system. This includes unresolved heterogeneities of mesoscale parameters and related boundaries, unaccounted advection processes, and other limitations of the SSCRAM system addressed by Hart and Cohen (2016). The diminished predictability may also be attributable to a decrease in overall convective predictability from strongly forced regimes to weakly forced regimes and the much lower occurrence of events during J–O. While testing these hypotheses is outside of the scope of this paper, the SSCRAM technique has served to highlight the challenge of attempting to discern the predictability of significant tornadoes during the June–October time period, based on a robust database. These hypotheses could collectively provide the foundation for additional research related to improving significant tornado forecasting.

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