SHORT-TERM HAZARD INTENSITY FORECASTING AT THE STORM PREDICTION CENTER — AN UPDATE

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1. INTRODUCTION

Recent efforts at the SPC have pursued more explicit nowcast and short-term predictions of tornado wind speed, peak severe gust, and maximum hail size *intensity*, referred to informally as meso-beta (β) and meso-gamma (γ) Mesoscale Convective Discussions (MCD). This initial work encouraged the examination of short-term all hazard intensity prediction via MCDs. A subset of MCDs issued by the SPC beginning in November 2017 included explicit quantitative information using a range of values rather than qualitative terms often used to describe intensity of the various hazards [e.g., 120 to 150 mph (EF2–EF3) vs. strong tornado, 55 to 70 mph vs. damaging wind, 2.0 to 3.5 inches in diameter hail size vs. very large hail]. Recent Spring Forecasting Experiments in the NOAA Hazardous Weather Testbed utilized peak intensity ranges of the individual hazards to highlight severe weather in a non-disseminated Mesoscale Convective Discussion product (SFE 2023, 2024). Preliminary results based on past event verification of the MCD forecasts indicate skill. A more systematic internal-SPC experiment began in April 2024 with continued evaluation of forecasts and severe report data used for verification as of autumn 2024. Additional evaluation is planned to assess the skill of explicit quantitative information on hazard peak intensity. A brief overview of methods and preliminary results of MCD verification during the April–June 2024 period are in sections 2 and 3. A forecast sequence of SPC experimental products containing an all-hazards Conditional Intensity Outlook, pre-watch MCD, Tornado Watch, and meso-β MCD are in section 4.

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2. METHODOLOGY

During the 3 April–30 June 2024 period, 1114 individual hazard forecasts by SPC forecasters—not disseminated publicly—containing peak intensity bin (PIB) information for tornadoes, hail, and thunderstorm gusts were archived from operationally issued MCDs. Different time lengths were examined based on a 4-hr, 5-hr, 6-hr period from MCD issuance, and from 3-hr time-lagged MCD expiration. Similar performance was noted between the different MCD valid time periods. Performance data presented herein will only include metrics from 4-hr valid PIB MCD periods.

a. Peak Intensity Bins

Both tornado and thunderstorm wind PIBs contained a lower and upper bound wind speed with 7 pre-defined overlapping ranges of wind speed (Table 1). All wind speed and hail size diameter values were limited to no more than 2 PIBs. Near the ends of the intensity spectrum for the individual hazards, only 1 PIB contains the upper tier and lower tier values. The highest PIB for tornado and thunderstorm wind is not equivalent to a Convective Outlook High Risk, but rather it is intended to be reserved for exceptionally rare high-end events and generally match present-day frequency of occurrence of those upper-tier tornado and thunderstorm wind forecasts. The inclusive wind speed ranges of each tornado PIB (i.e., 30 or 35 mph) were previously found to be operationally useful and not too large or small of a range, similarly to the size of the range output in the SPC Tornado qIDSS tool (Smith et al. 2022, their Fig. 5). Hail size diameter (inches) was stratified into 6 PIBs and this was partially due to a greater frequency of occurrence of giant hail, and it is congruent to Convective Outlooks not having as many categorical risk tiers as tornado and wind hazards (i.e., no hail High Risk category). The PIBs use internal SPC Conditional Intensity Convective Outlook probabilities and tiered intensity [i.e., Conditional Intensity Groups (CIG)] as a *first-guess* peak intensity. Also, NWS impact-based warnings (IBW) generally associated with the corresponding PIB and other frame-of-reference information are provided in Table 1.

TORNADO

Wind Speed (mph)	Conditional Intensity (outlook probability)	Typical IBW tag	Descriptor	1st Guess Environment	EF Range	EF-scale
≤ 95	CIG 0 - no hatch (≤ 2)	Base	weak	STP <1	0-1	0 (65-85 mph)
85–115	CIG 0 - no hatch (≥ 5)	Base	weak/strong	STP <1	0-2	1 (86-110 mph)
100–130	CIG 1 - single hatch (≤ 5)	Base/Considerable	weak/strong	STP 1+	1-2	2 (111-135 mph)
120–150	CIG 1 - single hatch (≥ 10)	Considerable	strong	STP 1+	2-3	
140–170	CIG 2 - double hatch (≤ 10)	Considerable/Catastrophic	intense	STP 4+	3-4	3 (136-165 mph)
155–190	CIG 2 - double hatch (≥ 15)	Catastrophic	intense/violent	STP 4+	3-4	4 (166-200 mph)
≥ 175	CIG 3 - triple hatch	Catastrophic-Emergency	violent/exceptionally rare	STP 7+	4-5	5 (201+ mph)

WIND

Wind Speed (mph)	Conditional Intensity (outlook probability)	Typical IBW tag	Descriptor	Coverage
≤ 60	CIG 0 - no hatch (≤ 5)	SPS/Severe	locally damaging/severe	localized to scattered
55–70	CIG 0 - no hatch (≥ 15)	Severe	severe	localized to scattered
65–80	CIG 1 - single hatch (≤ 15)	Severe/Considerable	severe/significant	localized to numerous
75–90	CIG 1 - single hatch (≥ 30)	Considerable/Destructive	significant	isolated to numerous
85–100	CIG 2 - double hatch (≤ 30)	Destructive	significant/intense	isolated to widespread
95–115	CIG 2 - double hatch (≥ 45)	Destructive	intense	scattered to widespread
≥ 110	CIG 3 - triple hatch	Destructive	exceptionally rare	widespread

HAIL

Size (inches)	Conditional Intensity (outlook probability)	Typical IBW tag
≤ 1.25	CIG 0 - no hatch (≤ 5)	SPS/Severe
1.00–1.75	CIG 0 - no hatch (≥ 15)	Severe
1.50–2.50	CIG 1 - single hatch (≤ 15)	Severe/Considerable
2.00–3.50	CIG 1 - single hatch (≥ 30)	Considerable/Destructive
2.75–4.25	CIG 2 - double hatch (≤ 30)	Destructive
≥ 4.00	CIG 2 - double hatch (≥ 45)	Destructive

Table 1. Peak intensity bin tables for Tornado, Wind, and Hail (EF-scale insert, top right).

b. Data and Verification Methods

Storm Data was utilized for the verification of each hazard. Tornadoes assigned a peak wind speed rating based on damage were almost exclusively associated to the nearest 5 mph increment as commonly listed in either Storm Data or the Damage Assessment Toolkit (Camp et al. 2010). However, some tornadoes listed a maximum wind speed range (i.e., 170–180 mph) and the maximum value was recorded for verification. The PIB was evaluated using the closest mid-value of the specific range selected by the issuing forecaster (e.g., 115 mph for a forecaster-selected 100–130mph predicted range), and then compared to the peak wind speed of the tornado. The resultant intensity forecasts were compared to the max hazard within any county/parish inside or touching the MCD polygon during a 4-hr period. For thunderstorm wind, Edwards et al. (2018) found by reducing wind gust estimations from people by 20%, these estimations matched instrument-measured observations. We have also applied this 0.8 coefficient to peak thunderstorm wind gust estimations if the highest wind report was not measured by an instrument. For EF-U tornadoes, where no damage occurred, the assigned peak wind speed was 65 mph. A PIB was considered a null event if no report occurred, or the peak thunderstorm wind gust < 45 mph or hail < 0.75 inch in diameter.

3. RESULTS

a. Tornado

The initial SPC goal for PIB MCD issuance is to verify within ±1 PIB ≥ 90%, and correctly forecast the same PIB ≥ 60% of the time. The 0–4 hour ± 1 PIB verification for 1114 MCDs that included all null events was 85% for hail, 87% for wind, and 90% for tornado (Table 2). The correct PIB was verified between 52% for wind to 68% for tornado forecasts. The first-guess PIB based on the previously issued Conditional Intensity Outlook verified 5–10% lower than the forecaster's PIB forecast. This highlights by the net positive adjustment made by forecasters in the initial months of the experiment.

Removing the null cases (Table 3) from MCD evaluation corresponds to considerably lower forecaster skill (i.e., 42% vs. 68%) to correctly forecast the appropriate tornado PIB. Forecasters provided a net positive adjustment in wind and hail PIB forecasts compared to the first-guess method.

The distribution of all forecast events for tornadoes, including null tornado events, more closely matches the distribution of tornado PIB counts compared to the first-guess data (Table 4). Likewise when considering only forecasts where tornadoes occurred, a similar but more aligned distribution to the tornado occurrence PIB is evident. A similar over-forecast count distribution is apparent for the first-guess severe wind and hail PIBs, compared to the forecaster's PIBs whether evaluating all issued forecasts or solely the forecasts from which a hazard occurred (Tables 5–6).

	± 1 Bin	Same Bin	≥ 1 Bin (Over)	≤ -1 Bin (Under)	Positive Adjust	Negative Adjust	Events
Tor FG	81%	62%	34%	4%			
Tor Fcst	90%	68%	22%	10%	22%	8%	307
Wind FG	81%	46%	46%	7%			
Wind Fcst	87%	52%	35%	13%	24%	11%	809
Hail FG	76%	47%	40%	13%			
Hail Fcst	85%	56%	28%	16%	25%	10%	676

Table 2. Tornado, Wind, and Hail verification for all issued forecasts for first guess (FG) and forecaster verification ± 1 PIB, same PIB, over-forecast PIB, under-forecast PIB, forecaster-over-the-loop positive adjustment to FG error, negative adjustment to FG error, and number of events.

	± 1 Bin	Same Bin	≥ 1 Bin (Over)	≤ -1 Bin (Under)	Positive Adjust	Negative Adjust	Events
Tor FG	75%	48%	36%	16%			
Tor Fcst	79%	42%	25%	33%	22%	24%	307
Wind FG	82%	50%	39%	10%			
Wind Fcst	89%	56%	26%	18%	23%	11%	809
Hail FG	80%	45%	34%	21%			
Hail Fcst	86%	53%	20%	27%	24%	12%	676

Table 3. Same as Table 2 except for only when individual hazards occurred.

Wind Speed (mph)	FG4h All	Fcst4h All	4h All Obs	FG4h Tor Occ	Fcst4h Tor Occ	4h Tor Occ Obs
Null or ≤ 95	605	734	887	66	97	80
85–115	192	202	91	61	76	91
100–130	136	94	77	55	57	77
120–150	130	61	37	83	56	37
140–170	6	14	13	4	13	13
155–190	45	9	9	38	8	9
≥ 175	NA	0	0	NA	0	0

Table 4. MCD Tornado forecast counts by PIB for all forecasts (left) and MCD Tornado forecasts when tornadoes occurred (right).

Wind Speed (mph)	FG4h All	Fcst4h All	4h All Obs	FG4h Wind Occ	Fcst4h Wind Occ	4h Wind Occ Obs
Null or ≤ 60	223	288	527	117	165	222
55–70	414	461	293	303	336	293
65–80	173	233	188	123	187	188
75–90	246	122	89	216	111	89
85–100	32	7	12	26	7	12
95–115	26	3	5	24	3	5
≥ 110	NA	0	0	NA	0	0

Table 5. Same as Table 4 except for Wind.

Size (inches)	FG4h All	Fcst4h All	4h All Obs	FG4h Hail Occ	Fcst4h Hail Occ	4h Hail Occ Obs
Null or ≤ 1.25	354	419	544	133	160	106
1.00–1.75	183	267	225	103	163	225
1.50–2.50	295	271	167	200	208	167
2.00–3.50	206	119	127	170	109	127
2.75–4.25	39	37	42	33	35	42
≥ 4.00	37	1	9	37	1	9

Table 6. Same as Table 4 except for Hail.

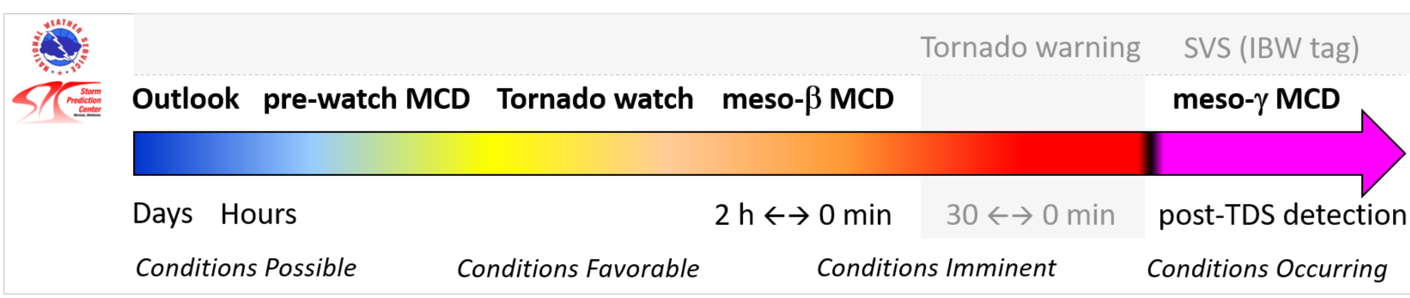


Figure 1. Idealized severe weather product timeline for National Weather Service local offices and Storm Prediction Center products.

4. FORECASTER NOTES

Recent efforts at the SPC have focused on hazard intensity and discussions pertaining to enhancing the existing SPC severe weather product suite. A proof-of-concept and forecast funnel from longer- to short-term forecast periods and smaller spatial areas is demonstrated in Fig. 1. The internal SPC Conditional Intensity Outlook was used as a basis for the first-guess PIB (Fig. 2). More specifically, the traditional hazard probabilities issued with the 6 May 2024 1630 UTC Convective Outlook feature Conditional Intensity Group (CIG) 1 and 2 highlights, which are graphically depicted using single and double-hatched severe highlights. A pre-watch MCD issued soon after highlighted the tornado risk with a qualitative term "intense" and using a parenthetical to associate with the EF-scale. MCD products typically lack explicit quantitative assessments of intensity for tornadoes, but historically often use qualitative terms to describe the threat (e.g., weak/brief, strong, intense, violent). A subsequent Particularly Dangerous Situation Tornado Watch (Fig. 4) also used the intense wording to emphasize the forecast tornado severity but provided no explicit quantification of the forecast tornado intensity. Lastly, a meso-β MCD was issued to communicate the imminent realization of tornado potential into a short-term tornado intensity forecast. The MCD text discussion in Fig. 5 only provided a qualitative characterization of the tornado threat (i.e., strong/ intense). However, the PIB information (e.g., 155–190 mph for tornado) selected by the issuing forecaster (not disseminated) is overlaid on the MCD #668's graphic and this graphic template may be used as a future prototype to convey the quantitative information selected by the forecaster. Evaluation of forecaster skill using additional MCD forecasts beyond April–June 2024 is currently ongoing as of late autumn 2024.

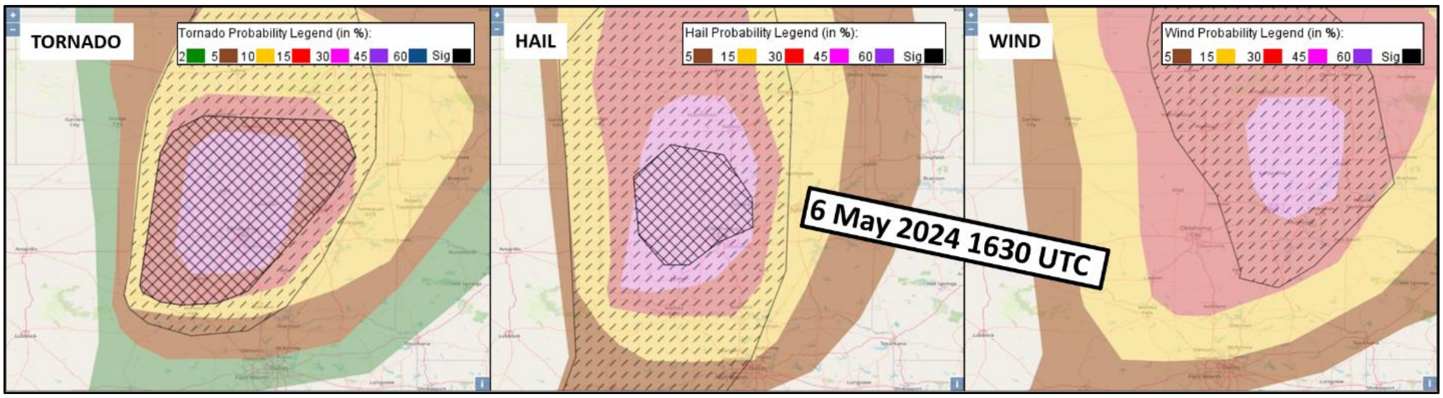
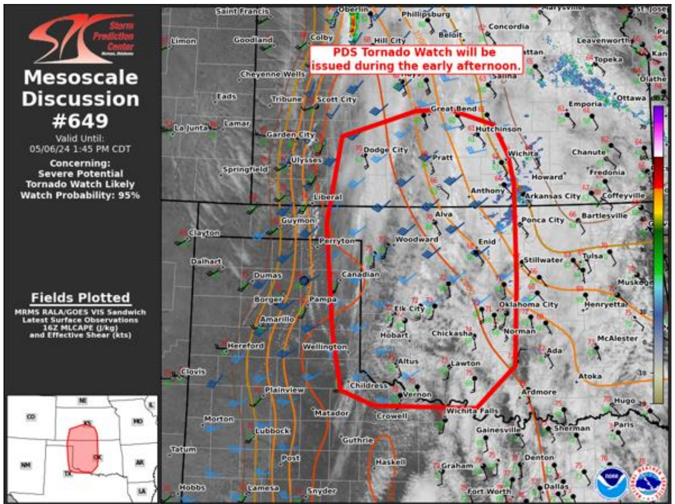


Figure 2. Conditional Intensity Outlook issued at 1630 UTC on 6 May 2024. Tornado (left), hail (middle), wind (right) with probability legend inserts upper right. Conditional Intensity Groups (CIG) 1 and 2 denoted by the stippled black polygons.



Mesoscale Discussion 0649
NWS Storm Prediction Center Norman OK
1147 AM CDT Mon May 06 2024

Areas affected...southern KS...western/central OK...and eastern TX Panhandle

Concerning...Severe potential...Tornado Watch likely

Valid 061647Z - 061845Z

Probability of Watch Issuance...95 percent

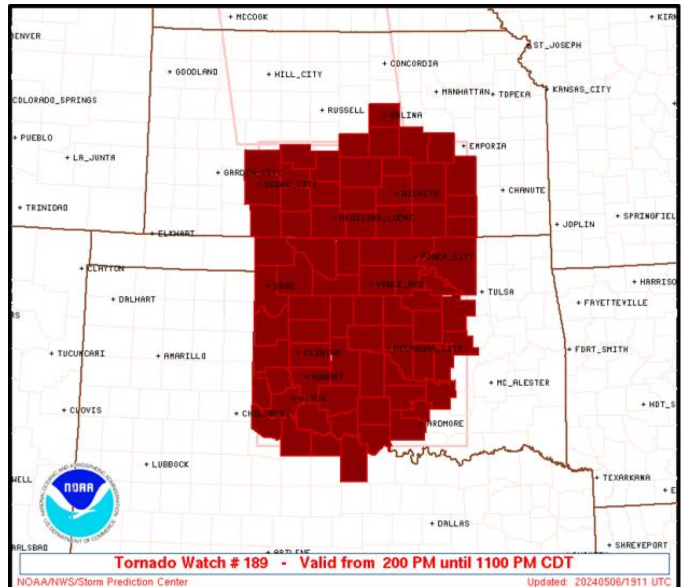
SUMMARY...PDS Tornado Watch issuance will be needed ahead of this portion of the dryline during the early afternoon. At least a few long-track, discrete supercells are expected, becoming capable of producing intense (EF3+) tornadoes.

DISCUSSION...16Z surface analysis placed the dryline from near Garden City, KS to Lubbock, TX, with the Pacific cold front lagging westward with southern extent in the southern High Plains. Airmass continues to destabilize ahead of the dryline, with MLCIN becoming weak into at least western OK and the TX Panhandle where boundary-layer warming has been more prominent in cloud breaks.

The expectation is for initial dryline/Pacific front development to occur in southwest KS and build south into the eastern TX Panhandle/western OK vicinity by late afternoon. Ample low to deep-layer shear will support several supercells with very large hail, tornadoes, and severe gusts probable. The impinging of an intense upper jet from NM into western OK over the next several hours, along with strengthening of low-level flow this evening, will yield an increasingly favorable kinematic environment for long-track and intense supercells capable of significant tornadoes, especially with southern extent in western/central OK.

..Grams/Smith.. 05/06/2024

Figure 3. Pre-Watch (Watch Potential) Mesoscale Convective Discussion (MCD) issued at 1647 UTC on 6 May 2024.



Tornado Watch Number 189
NWS Storm Prediction Center Norman OK
200 PM CDT Mon May 6 2024

The NWS Storm Prediction Center has issued a

* Tornado Watch for portions of
  Southern Kansas
  Western and Central Oklahoma
  Western North Texas

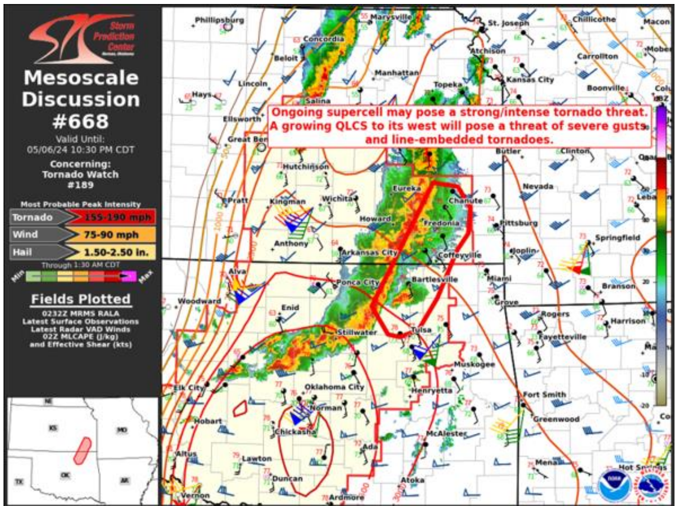
* Effective this Monday afternoon and evening from 200 PM until 1100 PM CDT.

...THIS IS A PARTICULARLY DANGEROUS SITUATION...

* Primary threats include...
  Numerous tornadoes expected with a few intense tornadoes likely
  Widespread large hail and scattered very large hail events to 4 inches in diameter likely
  Scattered damaging winds and isolated significant gusts to 75 mph likely

SUMMARY...Explosive thunderstorm development is forecast this afternoon along and east of a north to south oriented dryline. Given a very favorable environment for severe thunderstorms, intense supercells are expected to evolve. These storms are forecast to move east across the Watch area this afternoon through the late evening. The possibility exists for regenerative supercell development over central Oklahoma this evening. Initially large to giant hail is forecast with the initial supercell activity before the tornado risk increases. Intense tornadoes are probable especially as the atmosphere becomes very favorable for tornadoes late this afternoon and continuing through the evening.

Figure 4. Particularly Dangerous Situation (PDS) Tornado Watch issued at 1900 UTC on 6 May 2024.

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Mesoscale Discussion 0668
NWS Storm Prediction Center Norman OK
0935 PM CDT Mon May 06 2024

Areas affected...Northeast OK into southeast KS

Concerning...Tornado Watch 189...

Valid 070235Z - 070330Z

The severe weather threat for Tornado Watch 189 continues.

SUMMARY...A discrete supercell will pose a strong/intense tornado
threat, while a growing QLCS to the west may pose an increasing
threat for severe wind gusts and line-embedded tornadoes with time.

DISCUSSION...A discrete supercell has recently intensified across
northeast OK, and may be producing a strong to intense tornado
based on rotational velocity, environment, and TDS characteristics.
Strong instability and intense low-level shear/SRH (with 0-1 km SRH
increasing above 400 m2/s2 on the KINX VWP) will continue to support
intense tornado potential with this cell as it moves northeastward.

Farther north and west, a growing QLCS will pose an increasing
threat of severe wind gusts and line-embedded tornadoes as it moves
eastward. This QLCS will eventually tend to absorb the ongoing
tornadic cell and other discrete cells that may develop ahead of the
line, which would potentially increase the tornado threat in the
area of the QLCS where these mergers occur.

..Dean.. 05/07/2024
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Figure 5. Meso-β MCD with mock-up PIB scale (left menubar).

7. REFERENCES

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