Supplementary Material for: A Probabilistic Framework for Reconstructing Weather-Related Power Outage Frequency

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Supplementary figures

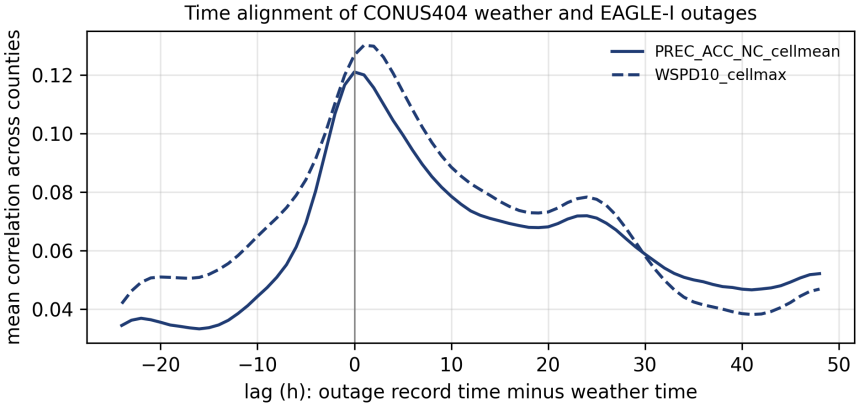


Fig. S1 Temporal alignment check between hourly outage observations and meteorological forcing. Cross-correlation is used to verify the common time base and the short response lag between weather conditions and reported outages.

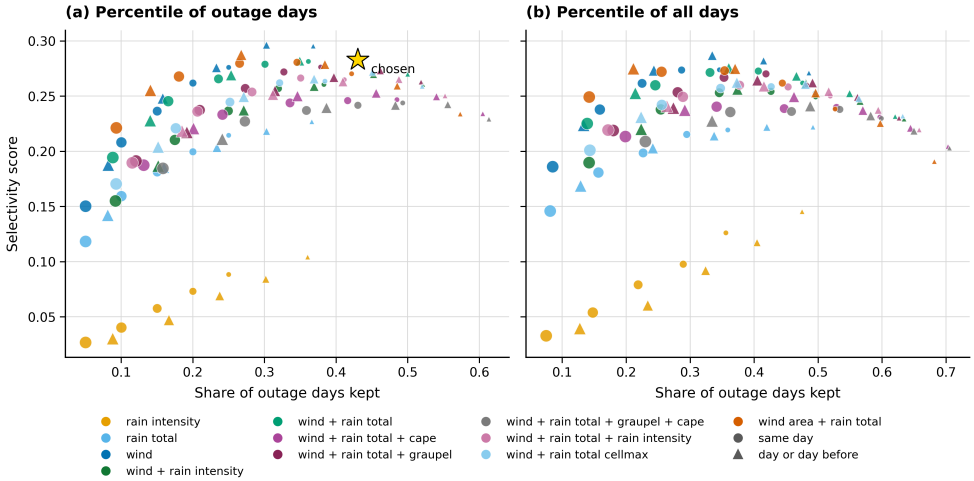


Fig. S2 Selectivity of 220 candidate definitions of a weather-related outage day, formed by crossing variable sets (color), percentile threshold (symbol size), threshold basis (panel), and timing rule (symbol shape). The selectivity score is the mean of the two Youden indices J_{8h} and J_{storm} defined in Section 2.3; the horizontal axis shows the share of outage days retained. The star marks the selected definition.

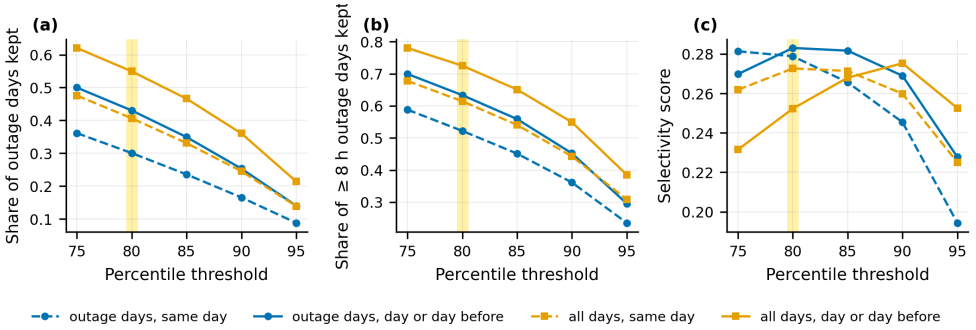


Fig. S3 Sensitivity of the selected variable set (wind and county-mean daily precipitation) to the percentile threshold, threshold basis, and timing rule. (a) Share of outage days retained. (b) Share of outage days lasting at least 8 h retained. (c) Selectivity score. The shaded band marks the selected 80th percentile.

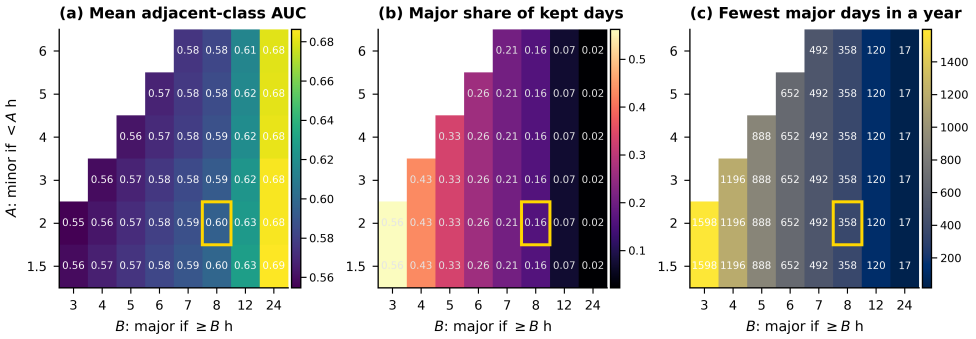


Fig. S4 Selection of severity class boundaries. For each combination of the minor upper bound A and the major lower bound B: (a) mean area under the curve with which the best weather variable separates adjacent classes; (b) share of retained outage days classified as major; (c) smallest number of major days in any complete year. The selected combination ($A = 2$ h, $B = 8$ h) is outlined.

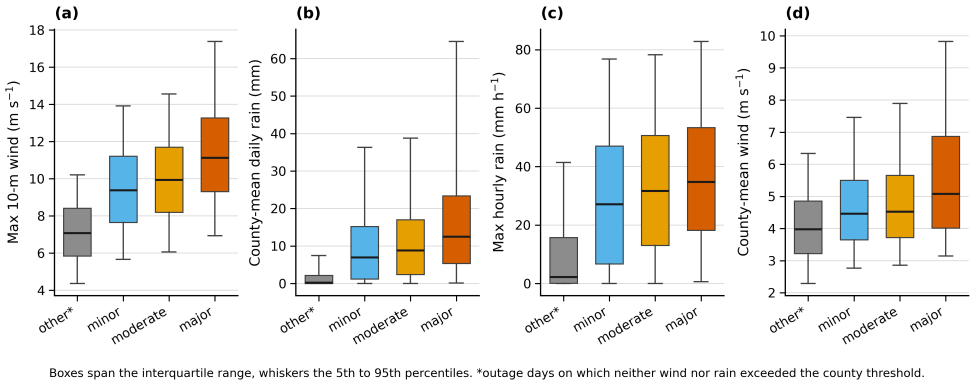


Fig. S5 Distribution of daily weather conditions by outage class, shown for outage days only. Boxes span the interquartile range, whiskers the 5th to 95th percentiles. "Other" denotes outage days on which neither wind nor precipitation exceeded the county threshold and which are therefore not classified as weather-related.

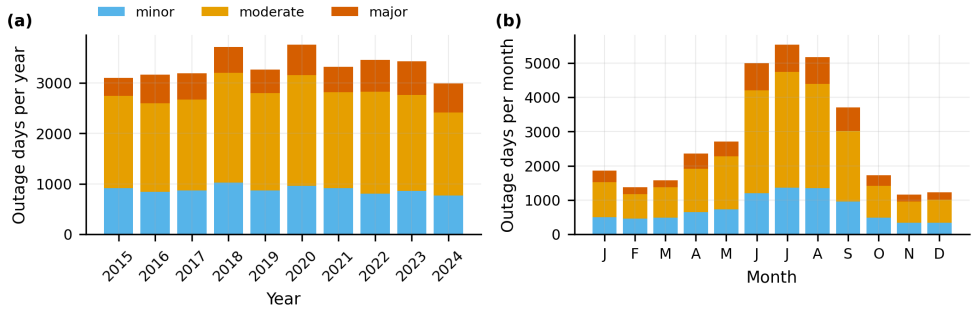


Fig. S6 Frequency of weather-related outage days by severity class, (a) by year and (b) by month, aggregated over all 67 counties.

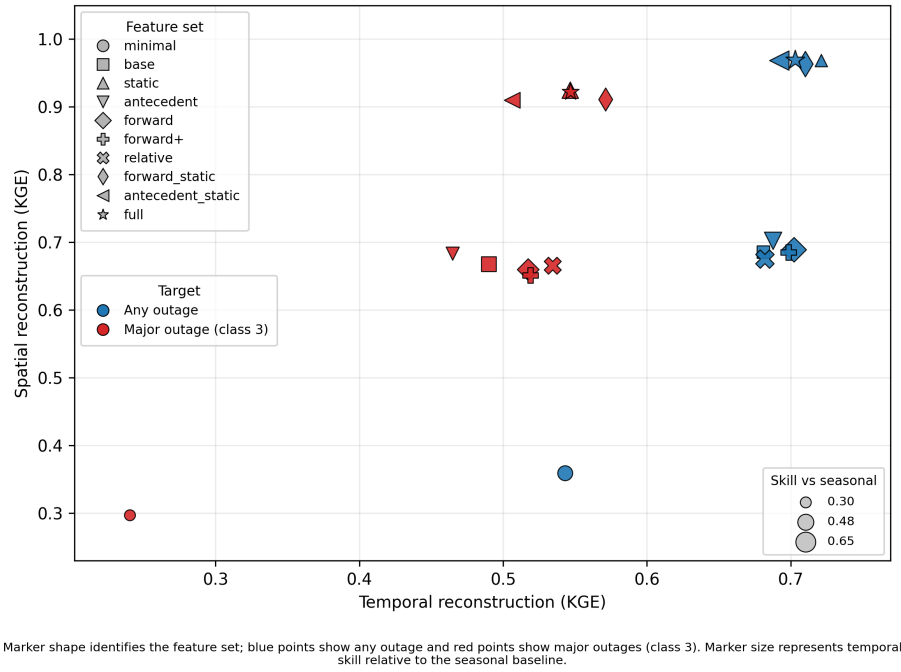


Fig. S7 Temporal and spatial skill of the ten predictor configurations. Marker shape identifies the configuration. Blue markers show all outage classes combined and red markers show major outages. Marker size shows the mean squared error skill of the annual predictions relative to the county-by-month baseline. Temporal KGE is computed from annual totals and spatial KGE from county totals over the whole period.

Supplementary tables

Table S1 Summary of the Florida county-level power outage dataset and outage characteristics, 1 January 2015–30 September 2024.

Quantity	**Value**
Counties	67
Period	2015-01-01 to 2024-09-30
County-days in the dataset	238,587
County-days with outage data (analysed)	232,568
Outage days (any duration $\geq$ 1 h)	77,660
Outage days per 1,000 county-days	333.9
Outage days $\geq$ 8 h (whole period)	8,550
Median daily outage duration (h)	2.75
90th / 99th percentile duration (h)	8.25 / 26.75
Share of outage days $\geq$ 8 h	0.11
Outage days in tropical-cyclone windows	4,722

Table S2 Sensitivity of the selected variable set (maximum 10 m wind or county-mean daily precipitation) to the percentile threshold and the timing rule, with percentiles computed over each county's outage days. Days kept and the capture of long outages do not depend on the tropical cyclone windows; the storm capture and the score do. The selected definition is shown in bold.

Timing	Percentile	Kept	$\geq$8 h kept	Storm kept	Score	CV	Outage days kept
day or day before	75	0.500	0.700	0.719	0.229	0.052	38,831
day or day before	**80**	0.430	0.634	0.652	0.232	0.050	33,425
day or day before	85	0.349	0.559	0.561	0.230	0.049	27,133
day or day before	90	0.254	0.452	0.449	0.216	0.057	19,688
day or day before	95	0.141	0.296	0.306	0.175	0.084	10,918
same day	75	0.361	0.588	0.558	0.232	0.051	28,065
same day	80	0.301	0.522	0.492	0.226	0.050	23,360
same day	85	0.236	0.451	0.414	0.216	0.054	18,318
same day	90	0.166	0.361	0.327	0.196	0.067	12,870
same day	95	0.088	0.236	0.216	0.151	0.103	6,863

Table S3 Six highest-scoring candidate definitions of a weather-related outage day, of 220 evaluated, with two stricter reference definitions. J_{8h} and J_{storm} are the Youden indices defined in Section 2.3 and the score is their mean; CV is the coefficient of variation of the retained share across years. Tropical cyclone windows follow the HURDAT2 rule given in Section 2.3. The selected definition is shown in bold. The full grid is shown in Fig. S2.

Rank	Definition	Kept	≥8 h	Storm	J_{8h}	J_{storm}	Score	CV
1	wind + rain total cellmax, p80, outage days, day or day before	0.451	0.651	0.678	0.225	0.242	0.234	0.067
2	wind, p75, outage days, day or day before	0.368	0.571	0.592	0.228	0.239	0.233	0.061
3	**wind + rain total, p80, outage days, day or day before**	0.430	0.634	0.652	0.228	0.236	0.232	0.050
4	wind + rain total, p75, outage days, same day	0.361	0.588	0.558	0.255	0.209	0.232	0.051
5	wind, p80, outage days, day or day before	0.303	0.500	0.528	0.221	0.240	0.231	0.062
6	wind + rain total + graupel, p75, outage days, same day	0.378	0.609	0.568	0.259	0.201	0.230	0.051
133	wind + rain total + graupel + cape, p90, outage days, same day (all drivers (p90; same day))	0.273	0.504	0.397	0.260	0.133	0.196	0.095
136	wind + rain total, p90, outage days, same day (strict (p90; same day))	0.166	0.361	0.327	0.220	0.171	0.196	0.067

Table S4 Six highest-ranked combinations of the minor upper bound A and the major lower bound B, of 38 evaluated. AUC values give the separability of adjacent classes by the best weather variable; the ranking criterion is their mean. The selected combination is shown in bold. The full grid is shown in Fig. S4.

Rank	Bounds (h)		Class size (county-days)				Separability (AUC)		
	A	B	Minor	Moderate	Major	Min. major/yr	Mod. vs minor	Major vs mod.	Mean
1	1.5	8	4,871	23,137	5,417	358	0.559	0.637	0.598
2	**2**	**8**	8,830	19,178	5,417	358	0.561	0.630	0.595
3	3	8	14,639	13,369	5,417	358	0.569	0.616	0.593
4	1.5	7	4,871	21,689	6,865	492	0.555	0.625	0.590
5	4	8	19,030	8,978	5,417	358	0.567	0.607	0.587
6	2	7	8,830	17,730	6,865	492	0.556	0.617	0.587

Table S5 Calibration of the predicted daily class probabilities over all 232,568 evaluated county-days. Expected counts are sums of predicted probabilities. ECE is the expected calibration error, the frequency-weighted mean absolute difference between predicted probability and observed frequency.

Class	Observed	Expected	Observed / expected	ECE
No weather-related outage	199,141	199,304	0.999	0.0048
Minor (1–2 h)	8,831	8,792	1.004	0.0045
Moderate (2–8 h)	19,179	19,202	0.999	0.0040
Major (≥8 h)	5,417	5,271	1.028	0.0020

Table S6 Annual frequency of weather-related outage days over the nine complete water years (October 2015 to September 2024). Counts are county-days summed over all 67 counties and all evaluated years. KGE is the Kling–Gupta efficiency, r the correlation across years, α the ratio of predicted to observed standard deviation, and β the ratio of the means. The last column gives the largest absolute annual deviation.

Class	Observed	Predicted	KGE	r	α	β	Max. dev. (%)
Minor (1–2 h)	8,055	8,040	0.81	0.96	0.81	1.00	5.2
Moderate (2–8 h)	17,555	17,519	0.60	0.86	0.62	1.00	9.4
Major (≥8 h)	5,089	4,867	0.32	0.43	0.63	0.96	19.4
All outage classes	30,699	30,427	0.68	0.82	0.74	0.99	8.2

Table S7 Skill by standard season, computed from seasonal totals across years. December is assigned to the following year's winter, and seasons that are incomplete at the ends of the record are excluded, which is why the number of seasons differs. Skill is the fraction of the seasonal baseline's mean squared error that the model removes.

Target	Season	Seasons	KGE	r	α	β	Skill
All outage classes	DJF	9	0.98	0.99	0.99	1.00	0.97
	MAM	10	0.86	0.92	0.89	0.99	0.86
	JJA	10	0.67	0.70	0.85	0.99	0.56
	SON	9	0.86	0.99	0.86	1.00	0.97
Major (≥8 h)	DJF	9	0.87	0.96	0.91	0.92	0.86
	MAM	10	0.59	0.74	0.68	0.96	0.61
	JJA	10	0.35	0.71	0.41	0.99	0.52
	SON	9	0.59	0.80	0.64	0.99	0.73

Table S8 Daily skill by weather regime. AUC is the area under the receiver operating characteristic curve for separating outage days from days without outages and for separating major from shorter outages among outage days. An AUC of 0.5 indicates no discrimination.

	Observed frequency				Model AUC		Baseline AUC	
Regime	County-days	Outage days	Outages per 1,000 days	Major share	Outage	Major	Outage	Major
Tropical-cyclone days	11,374	3,079	270.7	0.275	0.908	0.804	0.679	0.497
Other hurricane-season days	105,085	19,395	184.6	0.143	0.945	0.684	0.771	0.611
Off-season (Dec.–May)	116,109	10,953	94.3	0.164	0.963	0.748	0.663	0.549
All days	232,568	33,427	143.7	0.162	0.954	0.727	0.747	0.576

Table S9 Agreement between observed and predicted county totals over the whole evaluation period. Correlations are computed across the 67 counties. The last two columns give the median absolute deviation per county and the share of counties whose predicted total falls within 20% of the observed total.

Class	Observed	Predicted	r	Spearman	Median dev. (%)	Within 20% (%)
Minor (1–2 h)	8,831	8,792	0.988	0.969	5.3	96
Moderate (2–8 h)	19,179	19,202	0.997	0.997	3.1	93
Major ($\geq$8 h)	5,417	5,271	0.991	0.974	9.5	72