

Supplementary Information — A Leakage-Controlled Time-Series Forecasting Benchmark for GOES Soft X-ray and Proton Flux

1 Verification metrics — definitions

Event skill is computed on the 2×2 contingency table formed by thresholding both the forecast and the observation at the operational event threshold: a hits (TP), b false alarms (FP), c misses (FN), and d correct negatives (TN), with $N = a + b + c + d$ and event base rate $s = (a + c)/N$. Write the probability of detection $\text{POD} = H = a/(a + c)$ and the probability of false detection $\text{POFD} = F = b/(b + d)$. The reported metrics are defined as follows.

- **Precision** is the fraction of event forecasts that verify.

$$\text{Precision} = a/(a + b)$$

- **Frequency bias** (FB) is the ratio of forecast to observed event counts, unbiased at 1 and over-forecasting above 1.

$$\text{FB} = (a + b)/(a + c)$$

- **Critical success index** (CSI) denotes hits over hits, misses, and false alarms.

$$\text{CSI} = a/(a + b + c)$$

- **True skill statistic** (TSS) is the Peirce/Hanssen–Kuipers score. As $s \rightarrow 0$ the second term vanishes and $\text{TSS} \rightarrow \text{POD}$, which is the base-rate trap.

$$\text{TSS} = \frac{a}{a + c} - \frac{b}{b + d} = \text{POD} - \text{POFD}$$

- **Heidke skill score** (HSS) is an accuracy relative to random chance, drawing on all four cells, penalizing false alarms, and staying defined at every operating point.

$$\text{HSS} = \frac{2(ad - bc)}{(a + c)(c + d) + (a + b)(b + d)}$$

- **Matthews correlation** (MCC) is the balanced correlation between forecast and observation.

$$\text{MCC} = \frac{ad - bc}{\sqrt{(a + b)(a + c)(b + d)(c + d)}}$$

- **Symmetric extremal dependence index** (SEDI) is a base-rate-robust score for rare events [1], retained for the X-class tail where HSS and TSS both fall toward

zero. SEDI is undefined when H or F reaches 0 or 1, since the score then takes the logarithm of zero; a forecast that raises no false alarms ($F = 0$, precision = 1) or scores no hits ($H = 0$) therefore has no SEDI value, which is where cells are left blank in the per-granularity panels (Supplementary Tables [S6–S17](#)).

$$\text{SEDI} = \frac{\log F - \log H - \log(1 - F) + \log(1 - H)}{\log F + \log H + \log(1 - F) + \log(1 - H)}$$

2 Extending the benchmark with a new model

The benchmark is designed so that a new forecaster is added without touching the data pipeline, the training loop, or the evaluation code. A model name is resolved through a registry to a constructor, and the resulting network is wrapped in a forecast adapter that supplies the input window and selects the target channels, so a contributor writes only the network itself and one line of registration. Every model in the paper is registered by the same mechanism, and a re-run under an added model reuses the identical split, metrics, and logging.

2.1 The model contract

A backbone is a `Model(config) torch.nn.Module` whose forward takes the four THU-ML-style arguments and returns the full multichannel horizon,

$$\text{forward}(x_{\text{enc}}, x_{\text{mark_enc}}, x_{\text{dec}}, x_{\text{mark_dec}}) \rightarrow (B, \text{pred_len}, \text{enc_in}),$$

where B is the batch size. Before construction the framework sets `config.enc_in`, `config.dec_in`, and `config.c_out` to the number of input channels, so the network reads its width from the configuration rather than hard-coding it. The adapter builds zero-valued time-marks and decoder input, calls the forward, and slices the target channels from the output, so a backbone that ignores the mark and decoder arguments and emits all `enc_in` channels is sufficient. A model requiring a different call signature registers a new adapter kind instead.

2.2 A minimal example

The following per-channel linear forecaster is a complete, runnable model that meets the contract. The forecaster maps the input window to the forecast horizon independently per channel, and its shape handling is the pattern every backbone follows.

```
# tslib/model/mylinear.py
import torch.nn as nn

class Model(nn.Module):
    """Per-channel linear forecaster: seq_len -> pred_len."""
    def __init__(self, configs):
        super().__init__()
        self.proj = nn.Linear(configs.seq_len, configs.pred_len)

    def forward(self, x_enc, x_mark_enc, x_dec, x_mark_dec):
        # x_enc: (B, seq_len, enc_in)
        z = x_enc.transpose(1, 2) # (B, enc_in, seq_len)
        z = self.proj(z) # (B, enc_in, pred_len)
        return z.transpose(1, 2) # (B, pred_len, enc_in)
```

2.3 Registration and use

Registration adds the name to the central registry. The lazy-import route lists the module name, and the decorator route wraps an explicit constructor.

```
# tslib/model/registry.py -- lazy-import route
_LEGACY = [..., "mylinear"] # module tslib/model/mylinear.py

# -- or, decorator route for a custom constructor
from tslib.model.registry import register_model
@register_model("mylinear")
def _build(config):
    from tslib.model.mylinear import Model
    return Model(config)
```

The registered name is then passed on the command line, and the run reuses the benchmark split, metrics, and logging unchanged.

```
python main.py --models mylinear \
  --data_path data/kasi_swpc_xray_1m.parquet --target_col xrs_long \
  --seq_len 288 --pred_len 144 --n_fold 5 --transform log10 \
  --forecast_strategy direct --event_threshold 1e-5
```

The stored `kasi_swpc_xray_1m.parquet` holds the native 1-minute SXR series; `main.py` resamples every channel to the common 5-minute modelling grid (`--cadence_min`, default 5), so `--seq_len 288` spans 1 day.

2.4 Non-neural models

A statistical forecaster follows a separate, smaller contract under `--forecast_strategy statistic`: a class exposing `fit(history)` and `forecast(steps)`, registered with `register_stat`. The runner constructs it per test window and falls back to persistence on a failed or ill-shaped fit, so the built-in `arima`, `ar`, and `theta` baselines, together with any addition, can be evaluated on the same footing as the neural models. A classical self-regression comparison beyond

the persistence references reported in the main text is therefore available within the same leakage-controlled split, metric suite, and logging pipeline, and a practitioner who wants an autoregressive integrated moving average (ARIMA)-class baseline can obtain one with the framework without touching the evaluation code.

3 Intrinsic forecastability by regime

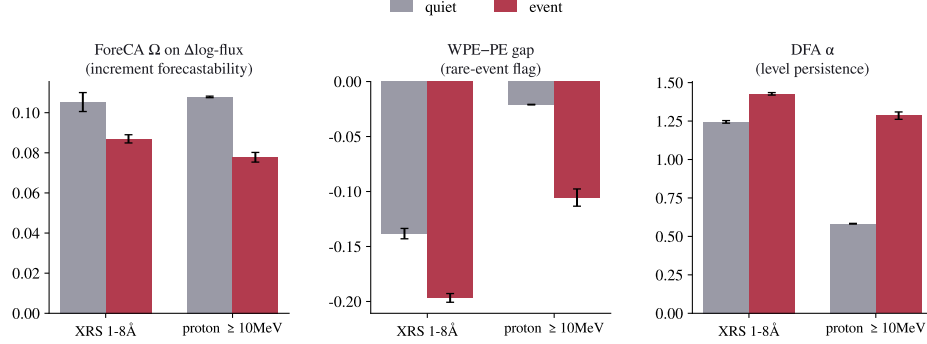


Fig. S1 Intrinsic forecastability by regime. ForeCA spectral predictability Ω on the differenced log-flux, the weighted-minus-plain permutation-entropy (WPE-PE) gap, and the detrended-fluctuation scaling exponent α , by quiet/event regime. Increment forecastability is low in both regimes, so a squared-error objective converges toward level persistence rather than predictable increments.

The three panels of Figure S1 contrast the quiet background with event windows on each target, supporting the main-text Results (Dataset Composition and Dynamical Regimes) and the Discussion. Increments are hard to forecast everywhere: the ForeCA spectral predictability Ω of the differenced log-flux is low, near 0.08–0.11, in both regimes and slightly lower still within events, so the low aggregate RMSE is carried by the persistent level, reflected in a high detrended-fluctuation exponent α , rather than by predictable increments. Event windows are nonetheless dynamically distinct: the weighted-minus-plain permutation-entropy (WPE-PE) gap deepens and the statistical complexity C rises, because a few rare high-amplitude ordinal patterns, the flare or SPE ramp, dominate. The quiet proton background instead occupies the high-entropy, low-complexity noise corner ($H \approx 0.95$, $\alpha \approx 0.58$), near-noise fluctuations over a flat level that persistence matches trivially. Aggregate RMSE is therefore carried by the forecastable level, while the rare, high-complexity event onsets are not foretold by flux history, the data-intrinsic basis for the SXR event-skill degradation.

4 Split validity

Supplementary Fig. S2 shows the per-fold event rate in each partition (train/validation/test) of the term-based rotating k-fold; every fold’s test set carries a non-zero, same-order event rate (cross-fold coefficient of variation 0.24–0.37), as summarized in the main-text Results.

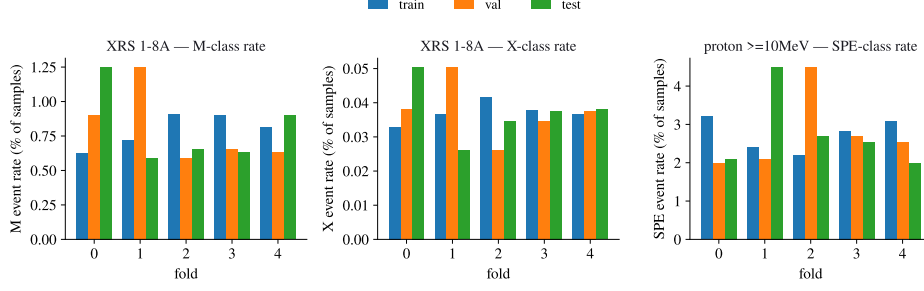


Fig. S2 Split validity. Per-fold event rate in each partition (train/val/test) of the term-based rotating k-fold; every fold’s test set carries a non-zero, same-order event rate (cross-fold coefficient of variation 0.24–0.37).

5 RMSE by historical and forecast horizon

The per-cell RMSE (log-flux) is maintained in `table/table_seq_pred_full.xlsx` (plain) and `table/table_seq_pred_full_ci.xlsx` (mean $\pm$ 95% CI across the five folds). Figure S3 plots the per-track RMSE against the historical horizon: SegRNN holds flat or improves as the history lengthens, while the linear and MLP families diverge by up to an order of magnitude.

Three tables report the 5-fold-mean RMSE by forecast target and model, one per historical horizon (Tables S1, S2, and S3 for the 1-, 3-, and 7-day historical horizons), each spanning the four forecast horizons with the lowest RMSE in each column set in bold; blank cells are the divergent, excluded xPatch runs at the 7-day historical horizon.

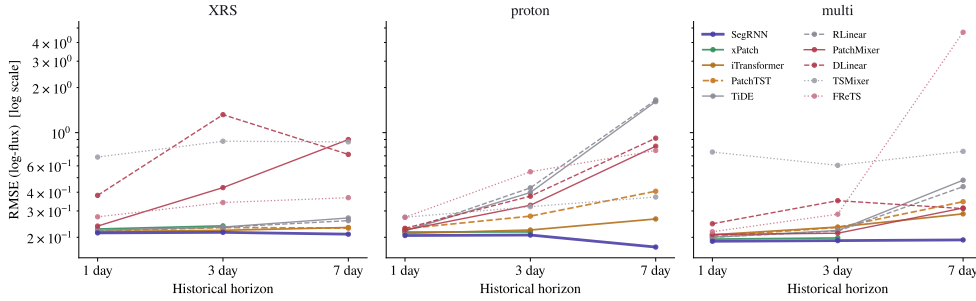


Fig. S3 RMSE versus historical horizon, by track. Per-track log-flux RMSE (5-fold mean, log scale) against the historical horizon at the 12 h forecast horizon, for (left) soft X-ray, (centre) proton, and (right) the multivariate track. SegRNN (bold) holds flat or improves as the history lengthens, whereas the linear and MLP families destabilize, their RMSE growing by up to an order of magnitude; the transformers degrade mildly. The full grid across all forecast horizons is in Tables S1–S3.

Target	Model	3 h	6 h	12 h	24 h
XRS 1–8 Å	SegRNN	0.180 ± 0.013	0.198 ± 0.013	0.214 ± 0.014	0.236 ± 0.016
	xPatch	0.206 ± 0.017	0.218 ± 0.014	0.227 ± 0.017	0.242 ± 0.018
	iTransformer	0.184 ± 0.012	0.201 ± 0.013	0.218 ± 0.015	0.240 ± 0.019
	PatchTST	0.207 ± 0.019	0.209 ± 0.014	0.220 ± 0.016	0.242 ± 0.019
	TiDE	0.190 ± 0.015	0.207 ± 0.015	0.223 ± 0.015	0.245 ± 0.019
	RLinear	0.190 ± 0.015	0.208 ± 0.015	0.223 ± 0.015	0.245 ± 0.019
	PatchMixer	0.213 ± 0.016	0.220 ± 0.025	0.238 ± 0.018	0.250 ± 0.018
	DLinear	0.259 ± 0.053	0.344 ± 0.076	0.381 ± 0.058	0.434 ± 0.089
	TSMixer	0.772 ± 0.387	0.890 ± 0.335	0.687 ± 0.217	0.765 ± 0.307
	FReTS	0.246 ± 0.057	0.254 ± 0.030	0.274 ± 0.019	0.312 ± 0.046
Proton	SegRNN	0.152 ± 0.009	0.170 ± 0.012	0.206 ± 0.025	0.264 ± 0.042
	xPatch	0.154 ± 0.009	0.175 ± 0.015	0.217 ± 0.030	0.274 ± 0.044
	iTransformer	0.150 ± 0.007	0.172 ± 0.013	0.212 ± 0.027	0.272 ± 0.049
	PatchTST	0.174 ± 0.009	0.199 ± 0.020	0.228 ± 0.032	0.287 ± 0.050
	TiDE	0.153 ± 0.008	0.178 ± 0.014	0.221 ± 0.026	0.316 ± 0.071
	RLinear	0.153 ± 0.008	0.175 ± 0.013	0.220 ± 0.025	0.312 ± 0.063
	PatchMixer	0.160 ± 0.010	0.183 ± 0.012	0.224 ± 0.023	0.288 ± 0.042
	DLinear	0.161 ± 0.009	0.194 ± 0.025	0.230 ± 0.036	0.313 ± 0.080
	TSMixer	0.205 ± 0.045	0.259 ± 0.055	0.272 ± 0.029	0.326 ± 0.072
	FReTS	0.192 ± 0.037	0.235 ± 0.059	0.272 ± 0.045	0.343 ± 0.055
Multivariate	SegRNN	0.151 ± 0.006	0.166 ± 0.008	0.188 ± 0.015	0.222 ± 0.023
	xPatch	0.160 ± 0.007	0.173 ± 0.010	0.195 ± 0.019	0.230 ± 0.031
	iTransformer	0.169 ± 0.007	0.184 ± 0.009	0.208 ± 0.018	0.240 ± 0.034
	PatchTST	0.164 ± 0.007	0.180 ± 0.005	0.204 ± 0.019	0.236 ± 0.032
	TiDE	0.162 ± 0.010	0.179 ± 0.013	0.200 ± 0.018	0.233 ± 0.031
	RLinear	0.162 ± 0.010	0.179 ± 0.013	0.200 ± 0.019	0.233 ± 0.031
	PatchMixer	0.167 ± 0.013	0.192 ± 0.016	0.209 ± 0.019	0.233 ± 0.032
	DLinear	0.177 ± 0.015	0.201 ± 0.014	0.246 ± 0.047	0.366 ± 0.086
	TSMixer	0.718 ± 0.094	0.743 ± 0.105	0.742 ± 0.204	0.735 ± 0.147
	FReTS	0.173 ± 0.018	0.200 ± 0.026	0.218 ± 0.021	0.256 ± 0.041

Table S1 RMSE by forecast horizon at a 1-day historical horizon. Log-flux RMSE as the 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$ (lower is better), by forecast target and model, across the four forecast horizons; the lowest mean RMSE in each column is in bold.

Target	Model	3 h	6 h	12 h	24 h
XRS 1–8 Å	SegRNN	0.181 ± 0.014	0.198 ± 0.015	0.216 ± 0.017	0.238 ± 0.020
	xPatch	0.218 ± 0.035	0.221 ± 0.015	0.238 ± 0.020	0.255 ± 0.026
	iTransformer	0.191 ± 0.013	0.207 ± 0.014	0.223 ± 0.017	0.248 ± 0.022
	PatchTST	0.228 ± 0.047	0.213 ± 0.022	0.232 ± 0.026	0.259 ± 0.034
	TiDE	0.195 ± 0.013	0.215 ± 0.014	0.234 ± 0.016	0.264 ± 0.023
	RLinear	0.196 ± 0.013	0.215 ± 0.013	0.233 ± 0.016	0.262 ± 0.022
	PatchMixer	0.206 ± 0.020	0.247 ± 0.086	0.429 ± 0.180	0.396 ± 0.222
	DLinear	1.015 ± 0.438	1.186 ± 0.325	1.318 ± 0.276	1.094 ± 0.088
	TSMixer	0.683 ± 0.324	0.838 ± 0.282	0.876 ± 0.442	0.659 ± 0.493
	FReTS	0.326 ± 0.077	0.322 ± 0.063	0.342 ± 0.058	0.361 ± 0.060
Proton	SegRNN	0.149 ± 0.008	0.169 ± 0.014	0.207 ± 0.032	0.268 ± 0.058
	xPatch	0.156 ± 0.013	0.176 ± 0.018	0.217 ± 0.033	0.284 ± 0.063
	iTransformer	0.162 ± 0.019	0.180 ± 0.021	0.224 ± 0.045	0.294 ± 0.066
	PatchTST	0.211 ± 0.038	0.230 ± 0.039	0.277 ± 0.077	0.321 ± 0.064
	TiDE	0.347 ± 0.316	0.510 ± 0.657	0.398 ± 0.297	0.644 ± 0.699
	RLinear	0.325 ± 0.291	0.562 ± 0.805	0.428 ± 0.363	0.616 ± 0.641
	PatchMixer	0.274 ± 0.173	0.342 ± 0.287	0.327 ± 0.165	0.451 ± 0.287
	DLinear	0.280 ± 0.163	0.304 ± 0.157	0.376 ± 0.233	0.422 ± 0.254
	TSMixer	0.298 ± 0.035	0.326 ± 0.086	0.320 ± 0.046	0.428 ± 0.143
	FReTS	0.311 ± 0.061	0.369 ± 0.117	0.548 ± 0.288	0.724 ± 0.342
Multivariate	SegRNN	0.150 ± 0.007	0.167 ± 0.011	0.190 ± 0.018	0.227 ± 0.032
	xPatch	0.162 ± 0.015	0.180 ± 0.023	0.198 ± 0.024	0.242 ± 0.039
	iTransformer	0.193 ± 0.010	0.213 ± 0.030	0.234 ± 0.043	0.271 ± 0.064
	PatchTST	0.180 ± 0.019	0.204 ± 0.024	0.233 ± 0.034	0.261 ± 0.031
	TiDE	0.171 ± 0.025	0.194 ± 0.047	0.222 ± 0.061	0.247 ± 0.054
	RLinear	0.170 ± 0.022	0.193 ± 0.044	0.220 ± 0.058	0.245 ± 0.053
	PatchMixer	0.170 ± 0.015	0.185 ± 0.017	0.213 ± 0.032	0.257 ± 0.045
	DLinear	0.205 ± 0.053	0.219 ± 0.041	0.351 ± 0.238	0.352 ± 0.164
	TSMixer	0.729 ± 0.376	0.663 ± 0.316	0.605 ± 0.236	0.623 ± 0.190
	FReTS	0.197 ± 0.043	0.218 ± 0.042	0.285 ± 0.049	0.319 ± 0.052

Table S2 RMSE by forecast horizon at a 3-day historical horizon. Log-flux RMSE as the 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$ (lower is better), by forecast target and model, across the four forecast horizons; the lowest mean RMSE in each column is in bold.

Target	Model	3 h	6 h	12 h	24 h
XRS 1–8 Å	SegRNN	0.175 ± 0.024	0.192 ± 0.028	0.210 ± 0.030	0.229 ± 0.035
	xPatch				
	iTransformer	0.208 ± 0.030	0.220 ± 0.042	0.233 ± 0.040	0.256 ± 0.049
	PatchTST	0.196 ± 0.025	0.216 ± 0.035	0.230 ± 0.047	0.251 ± 0.061
	TiDE	0.222 ± 0.063	0.234 ± 0.054	0.269 ± 0.074	0.318 ± 0.101
	RLinear	0.218 ± 0.056	0.232 ± 0.056	0.258 ± 0.066	0.314 ± 0.099
	PatchMixer	0.420 ± 0.313	0.392 ± 0.243	0.899 ± 0.685	1.497 ± 1.319
	DLinear	0.752 ± 0.327	0.846 ± 0.407	0.715 ± 0.395	0.704 ± 0.142
	TSMixer	0.891 ± 0.228	0.918 ± 0.335	0.867 ± 0.353	0.997 ± 0.230
	FReTS	0.366 ± 0.095	0.376 ± 0.092	0.368 ± 0.083	0.394 ± 0.083
Proton	SegRNN	0.095 ± 0.017	0.126 ± 0.027	0.172 ± 0.044	0.239 ± 0.072
	xPatch				
	iTransformer	0.238 ± 0.161	0.249 ± 0.119	0.265 ± 0.091	0.322 ± 0.102
	PatchTST	0.457 ± 0.167	0.405 ± 0.130	0.406 ± 0.184	0.441 ± 0.178
	TiDE	0.632 ± 0.435	0.893 ± 0.963	1.611 ± 3.105	1.150 ± 1.252
	RLinear	0.722 ± 0.556	1.052 ± 1.204	1.653 ± 2.867	1.202 ± 1.419
	PatchMixer	1.003 ± 0.702	0.682 ± 0.650	0.812 ± 1.100	2.008 ± 3.131
	DLinear	0.822 ± 0.637	0.867 ± 0.617	0.919 ± 0.563	0.894 ± 0.708
	TSMixer	0.315 ± 0.156	0.357 ± 0.136	0.372 ± 0.171	0.450 ± 0.181
	FReTS	0.587 ± 0.099	0.599 ± 0.268	0.760 ± 0.261	0.711 ± 0.069
Multivariate	SegRNN	0.145 ± 0.019	0.165 ± 0.028	0.192 ± 0.040	0.232 ± 0.062
	xPatch				
	iTransformer	0.255 ± 0.085	0.259 ± 0.070	0.287 ± 0.104	0.312 ± 0.119
	PatchTST	0.244 ± 0.079	0.311 ± 0.091	0.346 ± 0.252	0.349 ± 0.166
	TiDE	0.221 ± 0.039	0.314 ± 0.160	0.481 ± 0.255	0.634 ± 0.544
	RLinear	0.222 ± 0.034	0.308 ± 0.132	0.436 ± 0.243	0.634 ± 0.561
	PatchMixer	0.186 ± 0.039	0.227 ± 0.042	0.314 ± 0.172	0.342 ± 0.126
	DLinear	0.252 ± 0.057	0.304 ± 0.131	0.311 ± 0.126	0.330 ± 0.102
	TSMixer	0.644 ± 0.236	0.639 ± 0.323	0.750 ± 0.570	0.886 ± 0.547
	FReTS	3.369 ± 6.397	4.273 ± 9.707	4.682 ± 10.099	6.915 ± 16.405

Table S3 RMSE by forecast horizon at a 7-day historical horizon. Log-flux RMSE as the 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$ (lower is better), by forecast target and model, across the four forecast horizons; the lowest mean RMSE in each column is in bold. Blank cells are the divergent, excluded xPatch runs (xPatch diverges only at the 7-day historical horizon).

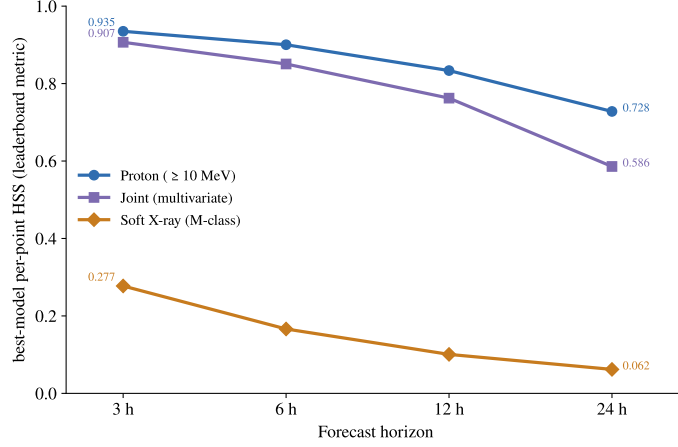


Fig. S4 Aggregate skill decay by track. Best-model per-point HSS (the leaderboard aggregate metric, base rate $\approx 0.8\%$) versus forecast horizon, averaged over the three historical horizons, for the proton, joint, and soft X-ray tracks. Proton decays shallowly and soft X-ray steeply; this per-point view shows the horizon slope, distinct from the persistence-relative per-day comparison in main-text Fig. 3.

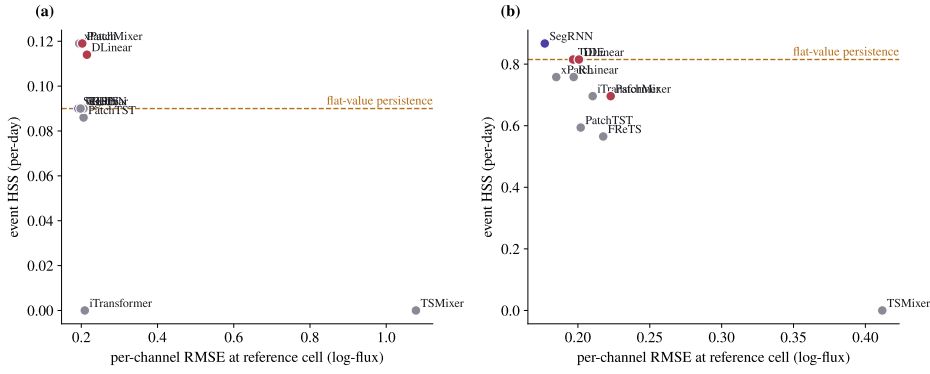


Fig. S5 The same decoupling on the multivariate track (reference fold). Per-model per-channel RMSE (x) versus per-day event HSS (y) for the joint track, one panel per channel ((a) XRS 1–8 Å; (b) proton > 10 MeV); the dashed line marks flat-value persistence. As on the univariate tracks (main-text Fig. 4), low RMSE does not buy event skill on the impulsive channel.

6 Event skill — horizon dependence and the multivariate track

Supplementary Fig. S4 shows the aggregate (per-point) skill decay by track, and Supplementary Fig. S5 applies the accuracy-versus-event-skill evaluation to the multivariate track; Supplementary Table S4 gives the underlying univariate-versus-multivariate event-skill numbers.

Model	SXR M-class 1–8 Å		Proton SPE ≥ 10 MeV	
	Univariate HSS / TSS	Multivariate HSS / TSS	Univariate HSS / TSS	Multivariate HSS / TSS
SegRNN	0.102 $\pm$ 0.029 / 0.061 $\pm$ 0.018	0.084 $\pm$ 0.047 / 0.050 $\pm$ 0.031	0.803 $\pm$ 0.030 / 0.682 $\pm$ 0.041	0.774 $\pm$ 0.031 / 0.643 $\pm$ 0.042
xPatch	0.095 $\pm$ 0.057 / 0.057 $\pm$ 0.036	0.090 $\pm$ 0.052 / 0.054 $\pm$ 0.035	0.781 $\pm$ 0.072 / 0.677 $\pm$ 0.104	0.755 $\pm$ 0.055 / 0.630 $\pm$ 0.082
iTransformer	0.087 $\pm$ 0.034 / 0.052 $\pm$ 0.021	0.053 $\pm$ 0.042 / 0.032 $\pm$ 0.027	0.766 $\pm$ 0.073 / 0.638 $\pm$ 0.094	0.702 $\pm$ 0.073 / 0.575 $\pm$ 0.098
PatchTST	0.066 $\pm$ 0.046 / 0.039 $\pm$ 0.028	0.051 $\pm$ 0.046 / 0.030 $\pm$ 0.029	0.775 $\pm$ 0.062 / 0.671 $\pm$ 0.076	0.732 $\pm$ 0.046 / 0.622 $\pm$ 0.068
TiDE	0.122 $\pm$ 0.051 / 0.073 $\pm$ 0.032	0.104 $\pm$ 0.050 / 0.063 $\pm$ 0.034	0.815 $\pm$ 0.041 / 0.728 $\pm$ 0.047	0.766 $\pm$ 0.036 / 0.657 $\pm$ 0.065
RLinear	0.111 $\pm$ 0.049 / 0.067 $\pm$ 0.031	0.094 $\pm$ 0.047 / 0.057 $\pm$ 0.032	0.816 $\pm$ 0.047 / 0.731 $\pm$ 0.054	0.761 $\pm$ 0.038 / 0.649 $\pm$ 0.066
PatchMixer	0.096 $\pm$ 0.058 / 0.058 $\pm$ 0.037	0.091 $\pm$ 0.057 / 0.055 $\pm$ 0.038	0.818 $\pm$ 0.042 / 0.780 $\pm$ 0.064	0.732 $\pm$ 0.075 / 0.622 $\pm$ 0.096
DLinear	0.216 $\pm$ 0.125 / 0.146 $\pm$ 0.102	0.194 $\pm$ 0.109 / 0.126 $\pm$ 0.085	0.798 $\pm$ 0.067 / 0.762 $\pm$ 0.053	0.763 $\pm$ 0.026 / 0.664 $\pm$ 0.067
TSMixer	0.000 $\pm$ 0.000 / 0.000 $\pm$ 0.000	0.000 $\pm$ 0.000 / 0.000 $\pm$ 0.000	0.594 $\pm$ 0.276 / 0.481 $\pm$ 0.321	0.194 $\pm$ 0.306 / 0.129 $\pm$ 0.210
FReTS	0.010 $\pm$ 0.007 / 0.006 $\pm$ 0.004	0.028 $\pm$ 0.043 / 0.017 $\pm$ 0.026	0.691 $\pm$ 0.118 / 0.577 $\pm$ 0.166	0.579 $\pm$ 0.222 / 0.437 $\pm$ 0.200
<i>flat-value persistence</i>	0.115 $\pm$ 0.031 / 0.069 $\pm$ 0.020	0.109 $\pm$ 0.038 / 0.066 $\pm$ 0.027	0.808 $\pm$ 0.039 / 0.690 $\pm$ 0.056	0.787 $\pm$ 0.035 / 0.657 $\pm$ 0.052

Table S4 Univariate versus multivariate event skill. Per-window HSS / TSS as $m_{\pm c}$, the mean and 95% confidence-interval half-width across the five folds, at the reference cell (1-day history, 12 h horizon), binarized at the M-class ($\geq 10^{-5}$ W m $^{-2}$) and solar-proton-event (≥ 10 pfu) thresholds. All three tracks are scored on the common 5-minute grid onto which the native 1-minute SXR channel is aggregated. Read each model against its row’s persistence floor; the wide intervals on the impulsive SXR channel show that no model resolves a per-window advantage over persistence.

Model	SXR M-class HSS / TSS	Proton SPE HSS / TSS
SegRNN	$0.096 \pm 0.039 / 0.057 \pm 0.027$	$0.774 \pm 0.109 / 0.650 \pm 0.144$
DLinear	$0.217 \pm 0.159 / 0.151 \pm 0.133$	$0.761 \pm 0.099 / 0.732 \pm 0.091$
PatchMixer	$0.105 \pm 0.052 / 0.063 \pm 0.034$	$0.787 \pm 0.059 / 0.752 \pm 0.127$
<i>flat-value persistence</i>	$0.112 \pm 0.032 / 0.067 \pm 0.023$	$0.785 \pm 0.089 / 0.664 \pm 0.126$
<i>occurrence-persistence</i>	$0.462 \pm 0.075 / 0.456 \pm 0.070$	$0.731 \pm 0.088 / 0.744 \pm 0.103$
<i>NOAA/SWPC operational [2, 3]</i>	$0.470 / 0.440$	$- / 0.49\text{--}0.69$

Table S5 Event skill against two persistence baselines and the operational forecast. Per-day HSS / TSS as $m_{\pm c}$, the mean and 95% confidence-interval half-width across the five folds, at the reference cell (1-day history, 12 h horizon), binarized at the M-class ($\geq 10^{-5} \text{ W m}^{-2}$) and solar-proton-event (≥ 10 pfu) thresholds; the operational row is a cited external reference. HSS penalizes false alarms and is the recommended metric; TSS is the community-standard flare-forecasting score, reported for comparability and to expose its degeneration at low base rate.

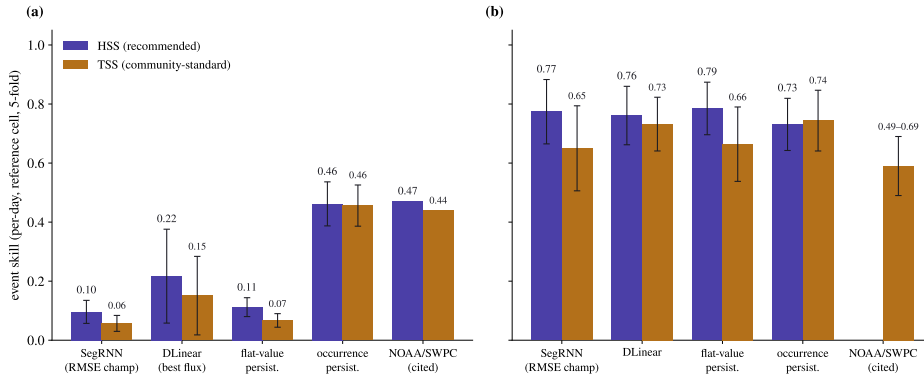


Fig. S6 Event skill against persistence floors and the operational reference. Reported as HSS (recommended) and TSS (community-standard), as the 5-fold mean with 95% confidence-interval error bars. (a) SXR M-class; (b) proton SPE, per-day at the reference cell (1-day history, 12 h horizon). On SXR M-class both flux models fall below occurrence-persistence and the operational NOAA/SWPC forecast in both metrics; on proton the models are competitive with the operational proton skill, published in TSS only (0.49–0.69, [3]), and sit within the persistence cluster. The same values are tabulated in Supplementary Table S5, and the full metric set at this reference cell appears in the per-granularity panels below.

7 Event skill against baselines and by granularity

Table S5 reports the per-day event skill at the reference cell (a 1-day historical horizon and a 12 h forecast horizon) for the two flux models against the persistence floors and the cited operational reference, in the recommended HSS and the community-standard TSS.

The full verification panel at the reference cell (12h horizon), by model and granularity, is maintained in `table/table_event_skill_panel.xlsx`; per-day bootstrap confidence intervals are in `table/rescore_perday.csv` (columns `model_CI`,

`naive_CI`). The per-granularity verification panels follow, ordered by forecast horizon and, within each, by target: at the 3-h horizon, Tables S6, S7, and S8; at 6 h, Tables S9, S10, and S11; at 12 h, Tables S12, S13, and S14; and at 24 h, Tables S15, S16, and S17. Each gives per-point / per-window / per-day skill, with the model rows separated from the persistence floors by a rule. Two persistence floors are reported, defined as in the main text (Skill versus Persistence and the Operational Reference): flat-value persistence holds the flux at its last observed value, and occurrence-persistence repeats the most recent event flag. At per-point granularity the two rules coincide, because thresholding the carried-forward value is identical to repeating the previous event flag, so a single flat-value floor is listed there. A blank cell marks a metric left undefined by that contingency table, for a reason that is itself diagnostic of the rare-event regime. SEDI is a ratio of logarithms of the hit rate (POD) and false-alarm rate (POFD) and requires both to lie strictly between 0 and 1, so it drops out whenever a model never hits, never misses, or never raises a false alarm; on the rarest per-day classes most models reach one of these limits. Precision and the Matthews correlation coefficient drop out only when a model issues no threshold-crossing forecast at all, leaving the forecast-positive margin empty; the most conservative models reach this state on the per-day X-class class, where the observed events themselves number only a few dozen across folds. The blanks therefore locate exactly the cells where the rare-event count is too small for a stable contingency-table score, which is part of what the granularity panel is meant to expose.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.922 $\pm$ 0.027	0.938 $\pm$ 0.017	0.887 $\pm$ 0.030	0.938 $\pm$ 0.017	0.983 $\pm$ 0.007	0.957 $\pm$ 0.011	0.965 $\pm$ 0.026
	xPatch	0.907 $\pm$ 0.035	0.914 $\pm$ 0.020	0.846 $\pm$ 0.034	0.914 $\pm$ 0.020	0.978 $\pm$ 0.010	0.924 $\pm$ 0.011	0.984 $\pm$ 0.037
	iTransformer	0.908 $\pm$ 0.035	0.921 $\pm$ 0.022	0.858 $\pm$ 0.039	0.922 $\pm$ 0.022	0.978 $\pm$ 0.010	0.939 $\pm$ 0.024	0.969 $\pm$ 0.045
	PatchTST	0.868 $\pm$ 0.024	0.866 $\pm$ 0.023	0.770 $\pm$ 0.037	0.866 $\pm$ 0.023	0.964 $\pm$ 0.007	0.869 $\pm$ 0.028	1.003 $\pm$ 0.031
	TiDE	0.912 $\pm$ 0.036	0.922 $\pm$ 0.020	0.859 $\pm$ 0.035	0.922 $\pm$ 0.020	0.979 $\pm$ 0.010	0.934 $\pm$ 0.012	0.979 $\pm$ 0.040
	RLinear	0.913 $\pm$ 0.034	0.920 $\pm$ 0.019	0.856 $\pm$ 0.032	0.920 $\pm$ 0.019	0.980 $\pm$ 0.009	0.931 $\pm$ 0.010	0.983 $\pm$ 0.039
	PatchMixer	0.867 $\pm$ 0.107	0.894 $\pm$ 0.069	0.815 $\pm$ 0.108	0.895 $\pm$ 0.067	0.965 $\pm$ 0.033	0.928 $\pm$ 0.025	0.936 $\pm$ 0.097
	DLinear	0.915 $\pm$ 0.034	0.912 $\pm$ 0.030	0.843 $\pm$ 0.050	0.913 $\pm$ 0.029	0.980 $\pm$ 0.009	0.913 $\pm$ 0.057	1.007 $\pm$ 0.086
	TSMixer	0.771 $\pm$ 0.226	0.794 $\pm$ 0.089	0.669 $\pm$ 0.121	0.807 $\pm$ 0.076	0.937 $\pm$ 0.064	0.874 $\pm$ 0.159	0.928 $\pm$ 0.437
	FReTS	0.659 $\pm$ 0.145	0.775 $\pm$ 0.101	0.644 $\pm$ 0.130	0.793 $\pm$ 0.084	0.908 $\pm$ 0.049	0.971 $\pm$ 0.028	0.682 $\pm$ 0.166
	<i>flat-value persistence</i>	0.936 $\pm$ 0.018	0.936 $\pm$ 0.015	0.884 $\pm$ 0.027	0.936 $\pm$ 0.015	0.986 $\pm$ 0.005	0.938 $\pm$ 0.013	1.000 $\pm$ 0.008
per-window	SegRNN	0.842 $\pm$ 0.048	0.910 $\pm$ 0.029	0.840 $\pm$ 0.047	0.913 $\pm$ 0.026	0.969 $\pm$ 0.010	0.996 $\pm$ 0.002	0.845 $\pm$ 0.048
	xPatch	0.873 $\pm$ 0.035	0.916 $\pm$ 0.021	0.850 $\pm$ 0.035	0.918 $\pm$ 0.020	0.970 $\pm$ 0.010	0.969 $\pm$ 0.008	0.902 $\pm$ 0.036
	iTransformer	0.840 $\pm$ 0.043	0.902 $\pm$ 0.025	0.826 $\pm$ 0.040	0.905 $\pm$ 0.023	0.964 $\pm$ 0.011	0.981 $\pm$ 0.014	0.857 $\pm$ 0.047
	PatchTST	0.816 $\pm$ 0.036	0.861 $\pm$ 0.025	0.763 $\pm$ 0.040	0.863 $\pm$ 0.024	0.949 $\pm$ 0.011	0.919 $\pm$ 0.019	0.891 $\pm$ 0.036
	TiDE	0.863 $\pm$ 0.049	0.913 $\pm$ 0.027	0.845 $\pm$ 0.045	0.915 $\pm$ 0.026	0.969 $\pm$ 0.012	0.976 $\pm$ 0.020	0.885 $\pm$ 0.058
	RLinear	0.874 $\pm$ 0.052	0.912 $\pm$ 0.023	0.843 $\pm$ 0.039	0.914 $\pm$ 0.022	0.971 $\pm$ 0.012	0.961 $\pm$ 0.035	0.912 $\pm$ 0.079
	PatchMixer	0.856 $\pm$ 0.069	0.904 $\pm$ 0.042	0.831 $\pm$ 0.069	0.906 $\pm$ 0.040	0.965 $\pm$ 0.019	0.965 $\pm$ 0.019	0.888 $\pm$ 0.071
	DLinear	0.902 $\pm$ 0.031	0.908 $\pm$ 0.036	0.837 $\pm$ 0.059	0.908 $\pm$ 0.035	0.976 $\pm$ 0.009	0.919 $\pm$ 0.067	0.988 $\pm$ 0.090
	TSMixer	0.725 $\pm$ 0.246	0.776 $\pm$ 0.113	0.650 $\pm$ 0.148	0.794 $\pm$ 0.092	0.930 $\pm$ 0.062	0.906 $\pm$ 0.147	0.840 $\pm$ 0.423
	FReTS	0.714 $\pm$ 0.129	0.813 $\pm$ 0.083	0.696 $\pm$ 0.113	0.825 $\pm$ 0.070	0.930 $\pm$ 0.030	0.969 $\pm$ 0.029	0.740 $\pm$ 0.152
	<i>flat-value persistence</i>	0.853 $\pm$ 0.035	0.917 $\pm$ 0.021	0.850 $\pm$ 0.035	0.920 $\pm$ 0.020	0.972 $\pm$ 0.008	0.997 $\pm$ 0.001	0.855 $\pm$ 0.035
	<i>occurrence-persistence</i>	0.913 $\pm$ 0.018	0.912 $\pm$ 0.015	0.844 $\pm$ 0.026	0.912 $\pm$ 0.015	0.979 $\pm$ 0.005	0.916 $\pm$ 0.014	1.000 $\pm$ 0.014
per-day	SegRNN	0.905 $\pm$ 0.088	0.940 $\pm$ 0.055	0.893 $\pm$ 0.098	0.942 $\pm$ 0.054	0.970 $\pm$ 0.015	0.984 $\pm$ 0.027	0.920 $\pm$ 0.080
	xPatch	0.889 $\pm$ 0.045	0.922 $\pm$ 0.038	0.860 $\pm$ 0.066	0.923 $\pm$ 0.038	0.972 $\pm$ 0.015	0.961 $\pm$ 0.038	0.927 $\pm$ 0.038
	iTransformer	0.879 $\pm$ 0.042	0.921 $\pm$ 0.044	0.858 $\pm$ 0.075	0.922 $\pm$ 0.045	0.964 $\pm$ 0.007	0.971 $\pm$ 0.060	0.907 $\pm$ 0.052
	PatchTST	0.817 $\pm$ 0.097	0.857 $\pm$ 0.052	0.757 $\pm$ 0.078	0.860 $\pm$ 0.048	0.950 $\pm$ 0.029	0.912 $\pm$ 0.054	0.902 $\pm$ 0.140
	TiDE	0.903 $\pm$ 0.050	0.931 $\pm$ 0.029	0.875 $\pm$ 0.051	0.932 $\pm$ 0.029	0.981 $\pm$ 0.012	0.965 $\pm$ 0.034	0.938 $\pm$ 0.066
	RLinear	0.917 $\pm$ 0.049	0.936 $\pm$ 0.028	0.883 $\pm$ 0.050	0.936 $\pm$ 0.028	0.985 $\pm$ 0.008	0.959 $\pm$ 0.049	0.960 $\pm$ 0.084
	PatchMixer	0.878 $\pm$ 0.115	0.908 $\pm$ 0.070	0.839 $\pm$ 0.113	0.910 $\pm$ 0.068	0.969 $\pm$ 0.033	0.947 $\pm$ 0.026	0.928 $\pm$ 0.112
	DLinear	0.936 $\pm$ 0.057	0.930 $\pm$ 0.026	0.873 $\pm$ 0.045	0.931 $\pm$ 0.026	0.986 $\pm$ 0.014	0.928 $\pm$ 0.045	1.014 $\pm$ 0.101
	TSMixer	0.729 $\pm$ 0.277	0.778 $\pm$ 0.146	0.655 $\pm$ 0.193	0.796 $\pm$ 0.124	0.936 $\pm$ 0.131	0.907 $\pm$ 0.138	0.839 $\pm$ 0.434
	FReTS	0.720 $\pm$ 0.120	0.820 $\pm$ 0.079	0.705 $\pm$ 0.111	0.831 $\pm$ 0.068	0.930 $\pm$ 0.058	0.973 $\pm$ 0.031	0.742 $\pm$ 0.134
	<i>flat-value persistence</i>	0.883 $\pm$ 0.091	0.935 $\pm$ 0.052	0.883 $\pm$ 0.091	0.938 $\pm$ 0.049		1.000 $\pm$ 0.000	0.883 $\pm$ 0.091
	<i>occurrence-persistence</i>	0.954 $\pm$ 0.027	0.925 $\pm$ 0.032	0.866 $\pm$ 0.055	0.926 $\pm$ 0.032	0.990 $\pm$ 0.007	0.900 $\pm$ 0.040	1.065 $\pm$ 0.037

Table S6 Verification panel — Proton SPE (3 h). Event skill at a 1-day historical horizon and a 3 h forecast horizon, on the univariate track binarized at the proton ≥ 10 pfu solar-proton-event threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.189 $\pm$ 0.090	0.298 $\pm$ 0.115	0.179 $\pm$ 0.081	0.382 $\pm$ 0.087	0.656 $\pm$ 0.058	0.807 $\pm$ 0.076	0.238 $\pm$ 0.121
	xPatch	0.097 $\pm$ 0.076	0.155 $\pm$ 0.106	0.087 $\pm$ 0.063	0.218 $\pm$ 0.079	0.519 $\pm$ 0.064	0.598 $\pm$ 0.194	0.189 $\pm$ 0.169
	iTransformer	0.193 $\pm$ 0.107	0.285 $\pm$ 0.121	0.171 $\pm$ 0.084	0.341 $\pm$ 0.087	0.625 $\pm$ 0.071	0.641 $\pm$ 0.051	0.309 $\pm$ 0.187
	PatchTST	0.118 $\pm$ 0.089	0.188 $\pm$ 0.121	0.108 $\pm$ 0.075	0.266 $\pm$ 0.083	0.573 $\pm$ 0.052	0.710 $\pm$ 0.207	0.190 $\pm$ 0.171
	TiDE	0.187 $\pm$ 0.108	0.282 $\pm$ 0.125	0.169 $\pm$ 0.088	0.351 $\pm$ 0.087	0.633 $\pm$ 0.070	0.711 $\pm$ 0.129	0.276 $\pm$ 0.185
	RLinear	0.173 $\pm$ 0.112	0.264 $\pm$ 0.133	0.157 $\pm$ 0.091	0.338 $\pm$ 0.091	0.624 $\pm$ 0.072	0.722 $\pm$ 0.157	0.257 $\pm$ 0.192
	PatchMixer	0.137 $\pm$ 0.094	0.214 $\pm$ 0.131	0.124 $\pm$ 0.082	0.277 $\pm$ 0.110	0.570 $\pm$ 0.079	0.631 $\pm$ 0.164	0.231 $\pm$ 0.155
	DLinear	0.178 $\pm$ 0.151	0.236 $\pm$ 0.111	0.139 $\pm$ 0.077	0.286 $\pm$ 0.071	0.589 $\pm$ 0.089	0.536 $\pm$ 0.139	0.392 $\pm$ 0.468
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.006		1.000	0.000 $\pm$ 0.000
	FRets	0.073 $\pm$ 0.136	0.094 $\pm$ 0.140	0.054 $\pm$ 0.085	0.134 $\pm$ 0.116	0.419 $\pm$ 0.148	0.387 $\pm$ 0.111	0.218 $\pm$ 0.438
	<i>flat-value persistence</i>	0.306 $\pm$ 0.086	0.306 $\pm$ 0.086	0.186 $\pm$ 0.061	0.306 $\pm$ 0.086	0.648 $\pm$ 0.075	0.312 $\pm$ 0.086	0.999 $\pm$ 0.005
per-window	SegRNN	0.162 $\pm$ 0.039	0.267 $\pm$ 0.056	0.161 $\pm$ 0.038	0.380 $\pm$ 0.052	0.620 $\pm$ 0.051	0.933 $\pm$ 0.032	0.174 $\pm$ 0.036
	xPatch	0.133 $\pm$ 0.066	0.219 $\pm$ 0.096	0.130 $\pm$ 0.064	0.325 $\pm$ 0.082	0.557 $\pm$ 0.060	0.870 $\pm$ 0.048	0.154 $\pm$ 0.078
	iTransformer	0.147 $\pm$ 0.047	0.242 $\pm$ 0.066	0.145 $\pm$ 0.045	0.346 $\pm$ 0.061	0.569 $\pm$ 0.055	0.856 $\pm$ 0.051	0.173 $\pm$ 0.049
	PatchTST	0.140 $\pm$ 0.044	0.232 $\pm$ 0.063	0.138 $\pm$ 0.042	0.344 $\pm$ 0.049	0.587 $\pm$ 0.039	0.901 $\pm$ 0.068	0.158 $\pm$ 0.056
	TiDE	0.173 $\pm$ 0.053	0.281 $\pm$ 0.074	0.171 $\pm$ 0.051	0.391 $\pm$ 0.059	0.626 $\pm$ 0.044	0.933 $\pm$ 0.007	0.186 $\pm$ 0.058
	RLinear	0.153 $\pm$ 0.055	0.254 $\pm$ 0.078	0.153 $\pm$ 0.053	0.370 $\pm$ 0.064	0.618 $\pm$ 0.044	0.944 $\pm$ 0.019	0.164 $\pm$ 0.061
	PatchMixer	0.158 $\pm$ 0.064	0.257 $\pm$ 0.086	0.155 $\pm$ 0.061	0.363 $\pm$ 0.068	0.597 $\pm$ 0.045	0.892 $\pm$ 0.076	0.179 $\pm$ 0.077
	DLinear	0.196 $\pm$ 0.101	0.293 $\pm$ 0.099	0.182 $\pm$ 0.076	0.372 $\pm$ 0.055	0.586 $\pm$ 0.047	0.785 $\pm$ 0.122	0.270 $\pm$ 0.207
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.014		1.000	0.000 $\pm$ 0.000
	FRets	0.086 $\pm$ 0.139	0.125 $\pm$ 0.168	0.076 $\pm$ 0.112	0.193 $\pm$ 0.139	0.410 $\pm$ 0.145	0.645 $\pm$ 0.109	0.157 $\pm$ 0.288
	<i>flat-value persistence</i>	0.169 $\pm$ 0.037	0.274 $\pm$ 0.052	0.167 $\pm$ 0.036	0.379 $\pm$ 0.047	0.603 $\pm$ 0.044	0.891 $\pm$ 0.026	0.190 $\pm$ 0.036
	<i>occurrence-persistence</i>	0.331 $\pm$ 0.055	0.330 $\pm$ 0.055	0.220 $\pm$ 0.044	0.330 $\pm$ 0.055	0.582 $\pm$ 0.053	0.359 $\pm$ 0.060	1.005 $\pm$ 0.007
per-day	SegRNN	0.159 $\pm$ 0.063	0.263 $\pm$ 0.092	0.159 $\pm$ 0.063	0.383 $\pm$ 0.080	0.579	0.975 $\pm$ 0.069	0.164 $\pm$ 0.063
	xPatch	0.117 $\pm$ 0.065	0.196 $\pm$ 0.102	0.116 $\pm$ 0.064	0.303 $\pm$ 0.103	0.516 $\pm$ 0.077	0.868 $\pm$ 0.175	0.139 $\pm$ 0.070
	iTransformer	0.125 $\pm$ 0.064	0.209 $\pm$ 0.099	0.124 $\pm$ 0.064	0.313 $\pm$ 0.104	0.497 $\pm$ 0.046	0.835 $\pm$ 0.131	0.149 $\pm$ 0.057
	PatchTST	0.135 $\pm$ 0.090	0.222 $\pm$ 0.137	0.134 $\pm$ 0.090	0.330 $\pm$ 0.135	0.498 $\pm$ 0.092	0.897 $\pm$ 0.187	0.154 $\pm$ 0.090
	TiDE	0.175 $\pm$ 0.095	0.281 $\pm$ 0.137	0.174 $\pm$ 0.096	0.391 $\pm$ 0.126	0.537 $\pm$ 0.087	0.940 $\pm$ 0.111	0.184 $\pm$ 0.086
	RLinear	0.151 $\pm$ 0.071	0.250 $\pm$ 0.105	0.151 $\pm$ 0.071	0.370 $\pm$ 0.094	0.545	0.967 $\pm$ 0.093	0.157 $\pm$ 0.069
	PatchMixer	0.140 $\pm$ 0.079	0.228 $\pm$ 0.113	0.137 $\pm$ 0.075	0.335 $\pm$ 0.089	0.584 $\pm$ 0.111	0.890 $\pm$ 0.142	0.165 $\pm$ 0.108
	DLinear	0.201 $\pm$ 0.072	0.304 $\pm$ 0.081	0.189 $\pm$ 0.057	0.381 $\pm$ 0.060	0.591 $\pm$ 0.062	0.778 $\pm$ 0.145	0.274 $\pm$ 0.149
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.077 $\pm$ 0.123	0.106 $\pm$ 0.142	0.065 $\pm$ 0.091	0.159 $\pm$ 0.145	0.418 $\pm$ 0.187	0.507 $\pm$ 0.458	0.199 $\pm$ 0.359
	<i>flat-value persistence</i>	0.157 $\pm$ 0.095	0.256 $\pm$ 0.138	0.157 $\pm$ 0.096	0.366 $\pm$ 0.128	0.518 $\pm$ 0.012	0.925 $\pm$ 0.139	0.170 $\pm$ 0.090
	<i>occurrence-persistence</i>	0.329 $\pm$ 0.081	0.341 $\pm$ 0.092	0.228 $\pm$ 0.069	0.343 $\pm$ 0.094	0.586 $\pm$ 0.091	0.393 $\pm$ 0.136	0.938 $\pm$ 0.298

Table S7 Verification panel — XRS M-class (3 h). Event skill at a 1-day historical horizon and a 3 h forecast horizon, on the univariate track binarized at the M-class ($\geq 10^{-5}$ W m $^{-2}$) threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.048 $\pm$ 0.031	0.090 $\pm$ 0.053	0.048 $\pm$ 0.030	0.190 $\pm$ 0.059	0.606 $\pm$ 0.047	0.799 $\pm$ 0.120	0.063 $\pm$ 0.046
	xPatch	0.008 $\pm$ 0.008	0.015 $\pm$ 0.015	0.008 $\pm$ 0.008	0.079 $\pm$ 0.042	0.531 $\pm$ 0.071	0.939 $\pm$ 0.089	0.008 $\pm$ 0.008
	iTransformer	0.024 $\pm$ 0.010	0.045 $\pm$ 0.018	0.023 $\pm$ 0.010	0.106 $\pm$ 0.048	0.515 $\pm$ 0.051	0.498 $\pm$ 0.322	0.055 $\pm$ 0.033
	PatchTST	0.010 $\pm$ 0.014	0.019 $\pm$ 0.028	0.010 $\pm$ 0.014	0.082 $\pm$ 0.060	0.518 $\pm$ 0.067	0.815 $\pm$ 0.290	0.016 $\pm$ 0.028
	TiDE	0.033 $\pm$ 0.014	0.063 $\pm$ 0.027	0.033 $\pm$ 0.014	0.166 $\pm$ 0.042	0.591 $\pm$ 0.037	0.857 $\pm$ 0.073	0.038 $\pm$ 0.015
	RLinear	0.018 $\pm$ 0.014	0.036 $\pm$ 0.026	0.018 $\pm$ 0.014	0.129 $\pm$ 0.048	0.597 $\pm$ 0.119	0.972 $\pm$ 0.067	0.019 $\pm$ 0.015
	PatchMixer	0.012 $\pm$ 0.010	0.023 $\pm$ 0.019	0.012 $\pm$ 0.010	0.074 $\pm$ 0.061	0.471 $\pm$ 0.114	0.582 $\pm$ 0.528	0.044 $\pm$ 0.050
	DLinear	0.034 $\pm$ 0.016	0.065 $\pm$ 0.028	0.034 $\pm$ 0.015	0.155 $\pm$ 0.030	0.578 $\pm$ 0.038	0.744 $\pm$ 0.204	0.051 $\pm$ 0.042
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.001 $\pm$ 0.002	0.002 $\pm$ 0.004	0.001 $\pm$ 0.002	0.008 $\pm$ 0.017	0.311 $\pm$ 0.121	0.054 $\pm$ 0.129	0.025 $\pm$ 0.034
	<i>flat-value persistence</i>	0.096 $\pm$ 0.040	0.096 $\pm$ 0.040	0.051 $\pm$ 0.022	0.096 $\pm$ 0.040	0.551 $\pm$ 0.065	0.096 $\pm$ 0.040	0.998 $\pm$ 0.076
per-window	SegRNN	0.078 $\pm$ 0.035	0.142 $\pm$ 0.057	0.077 $\pm$ 0.034	0.258 $\pm$ 0.052	0.605 $\pm$ 0.035	0.873 $\pm$ 0.032	0.090 $\pm$ 0.043
	xPatch	0.027 $\pm$ 0.032	0.052 $\pm$ 0.059	0.027 $\pm$ 0.032	0.146 $\pm$ 0.086	0.547 $\pm$ 0.129	0.925 $\pm$ 0.123	0.030 $\pm$ 0.033
	iTransformer	0.044 $\pm$ 0.012	0.081 $\pm$ 0.020	0.042 $\pm$ 0.011	0.150 $\pm$ 0.043	0.490 $\pm$ 0.047	0.521 $\pm$ 0.229	0.091 $\pm$ 0.037
	PatchTST	0.029 $\pm$ 0.036	0.054 $\pm$ 0.064	0.028 $\pm$ 0.034	0.148 $\pm$ 0.088	0.536 $\pm$ 0.060	0.801 $\pm$ 0.333	0.048 $\pm$ 0.074
	TiDE	0.073 $\pm$ 0.027	0.135 $\pm$ 0.046	0.073 $\pm$ 0.027	0.251 $\pm$ 0.056	0.603 $\pm$ 0.054	0.870 $\pm$ 0.091	0.084 $\pm$ 0.024
	RLinear	0.043 $\pm$ 0.023	0.082 $\pm$ 0.042	0.043 $\pm$ 0.023	0.202 $\pm$ 0.053	0.611 $\pm$ 0.129	0.986 $\pm$ 0.031	0.044 $\pm$ 0.024
	PatchMixer	0.038 $\pm$ 0.021	0.070 $\pm$ 0.037	0.037 $\pm$ 0.020	0.147 $\pm$ 0.066	0.504 $\pm$ 0.076	0.666 $\pm$ 0.420	0.085 $\pm$ 0.085
	DLinear	0.076 $\pm$ 0.021	0.137 $\pm$ 0.033	0.074 $\pm$ 0.019	0.239 $\pm$ 0.039	0.587 $\pm$ 0.054	0.774 $\pm$ 0.198	0.104 $\pm$ 0.053
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.007 $\pm$ 0.012	0.012 $\pm$ 0.023	0.006 $\pm$ 0.012	0.031 $\pm$ 0.055	0.375 $\pm$ 0.061	0.121 $\pm$ 0.204	0.052 $\pm$ 0.064
	<i>flat-value persistence</i>	0.092 $\pm$ 0.031	0.164 $\pm$ 0.049	0.090 $\pm$ 0.030	0.267 $\pm$ 0.051	0.602 $\pm$ 0.044	0.781 $\pm$ 0.049	0.117 $\pm$ 0.030
	<i>occurrence-persistence</i>	0.103 $\pm$ 0.029	0.103 $\pm$ 0.028	0.056 $\pm$ 0.016	0.103 $\pm$ 0.028	0.457 $\pm$ 0.052	0.105 $\pm$ 0.029	1.002 $\pm$ 0.064
per-day	SegRNN	0.050 $\pm$ 0.139	0.080 $\pm$ 0.222	0.050 $\pm$ 0.139	0.499		1.000	0.050 $\pm$ 0.139
	xPatch	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	iTransformer	0.050 $\pm$ 0.139	0.080 $\pm$ 0.222	0.050 $\pm$ 0.139	0.249 $\pm$ 0.694		0.500 $\pm$ 1.388	0.150 $\pm$ 0.278
	PatchTST	-0.000 $\pm$ 0.001	-0.000 $\pm$ 0.001	0.000 $\pm$ 0.000	-0.002		0.000	0.200 $\pm$ 0.555
	TiDE	0.050 $\pm$ 0.139	0.080 $\pm$ 0.222	0.050 $\pm$ 0.139	0.499		1.000	0.050 $\pm$ 0.139
	RLinear	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	PatchMixer	0.050 $\pm$ 0.139	0.079 $\pm$ 0.222	0.050 $\pm$ 0.139	0.248 $\pm$ 0.695		0.500 $\pm$ 1.388	0.100 $\pm$ 0.170
	DLinear	0.050 $\pm$ 0.139	0.080 $\pm$ 0.222	0.050 $\pm$ 0.139	0.499		1.000	0.050 $\pm$ 0.139
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	-0.000 $\pm$ 0.001	-0.000 $\pm$ 0.001	0.000 $\pm$ 0.000	-0.002		0.000	0.050 $\pm$ 0.139
	<i>flat-value persistence</i>	0.050 $\pm$ 0.139	0.080 $\pm$ 0.222	0.050 $\pm$ 0.139	0.499		1.000	0.050 $\pm$ 0.139
	<i>occurrence-persistence</i>	0.098 $\pm$ 0.278	0.112 $\pm$ 0.318	0.080 $\pm$ 0.222	0.114 $\pm$ 0.321	0.833	0.133 $\pm$ 0.370	0.667 $\pm$ 0.625

Table S8 Verification panel — XRS X-class (3 h). Event skill at a 1-day historical horizon and a 3 h forecast horizon, on the univariate track binarized at the X-class ($\geq 10^{-4}$ W m $^{-2}$) threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.881 $\pm$ 0.025	0.905 $\pm$ 0.024	0.831 $\pm$ 0.039	0.905 $\pm$ 0.024	0.971 $\pm$ 0.008	0.934 $\pm$ 0.025	0.946 $\pm$ 0.016
	xPatch	0.859 $\pm$ 0.051	0.875 $\pm$ 0.046	0.785 $\pm$ 0.071	0.875 $\pm$ 0.045	0.962 $\pm$ 0.018	0.897 $\pm$ 0.057	0.962 $\pm$ 0.069
	iTransformer	0.862 $\pm$ 0.067	0.884 $\pm$ 0.037	0.797 $\pm$ 0.058	0.885 $\pm$ 0.035	0.964 $\pm$ 0.020	0.913 $\pm$ 0.047	0.949 $\pm$ 0.105
	PatchTST	0.851 $\pm$ 0.051	0.832 $\pm$ 0.038	0.721 $\pm$ 0.056	0.833 $\pm$ 0.038	0.956 $\pm$ 0.019	0.820 $\pm$ 0.053	1.048 $\pm$ 0.091
	TiDE	0.845 $\pm$ 0.081	0.867 $\pm$ 0.053	0.772 $\pm$ 0.080	0.868 $\pm$ 0.051	0.957 $\pm$ 0.026	0.895 $\pm$ 0.019	0.946 $\pm$ 0.075
	RLinear	0.860 $\pm$ 0.051	0.876 $\pm$ 0.031	0.785 $\pm$ 0.050	0.876 $\pm$ 0.031	0.962 $\pm$ 0.015	0.897 $\pm$ 0.012	0.961 $\pm$ 0.048
	PatchMixer	0.849 $\pm$ 0.080	0.864 $\pm$ 0.052	0.768 $\pm$ 0.079	0.865 $\pm$ 0.051	0.958 $\pm$ 0.027	0.885 $\pm$ 0.034	0.964 $\pm$ 0.088
	DLinear	0.884 $\pm$ 0.044	0.844 $\pm$ 0.047	0.738 $\pm$ 0.069	0.846 $\pm$ 0.045	0.967 $\pm$ 0.015	0.813 $\pm$ 0.076	1.101 $\pm$ 0.131
	TSMixer	0.484 $\pm$ 0.371	0.590 $\pm$ 0.325	0.466 $\pm$ 0.352	0.640 $\pm$ 0.271	0.802 $\pm$ 0.179	0.925 $\pm$ 0.073	0.520 $\pm$ 0.385
	FRets	0.538 $\pm$ 0.186	0.673 $\pm$ 0.147	0.524 $\pm$ 0.167	0.709 $\pm$ 0.117	0.861 $\pm$ 0.073	0.966 $\pm$ 0.038	0.561 $\pm$ 0.214
	<i>flat-value persistence</i>	0.902 $\pm$ 0.030	0.901 $\pm$ 0.024	0.825 $\pm$ 0.040	0.901 $\pm$ 0.024	0.975 $\pm$ 0.009	0.902 $\pm$ 0.019	1.003 $\pm$ 0.014
per-window	SegRNN	0.770 $\pm$ 0.038	0.864 $\pm$ 0.024	0.768 $\pm$ 0.038	0.872 $\pm$ 0.022	0.952 $\pm$ 0.010	0.996 $\pm$ 0.002	0.773 $\pm$ 0.038
	xPatch	0.800 $\pm$ 0.083	0.868 $\pm$ 0.051	0.775 $\pm$ 0.076	0.873 $\pm$ 0.046	0.949 $\pm$ 0.026	0.962 $\pm$ 0.032	0.833 $\pm$ 0.098
	iTransformer	0.775 $\pm$ 0.062	0.859 $\pm$ 0.039	0.760 $\pm$ 0.058	0.866 $\pm$ 0.034	0.945 $\pm$ 0.017	0.976 $\pm$ 0.022	0.795 $\pm$ 0.071
	PatchTST	0.781 $\pm$ 0.060	0.835 $\pm$ 0.033	0.726 $\pm$ 0.049	0.838 $\pm$ 0.032	0.936 $\pm$ 0.020	0.909 $\pm$ 0.051	0.865 $\pm$ 0.103
	TiDE	0.814 $\pm$ 0.050	0.874 $\pm$ 0.029	0.784 $\pm$ 0.047	0.878 $\pm$ 0.028	0.953 $\pm$ 0.014	0.955 $\pm$ 0.049	0.856 $\pm$ 0.084
	RLinear	0.816 $\pm$ 0.052	0.876 $\pm$ 0.031	0.786 $\pm$ 0.049	0.880 $\pm$ 0.029	0.953 $\pm$ 0.015	0.955 $\pm$ 0.039	0.857 $\pm$ 0.074
	PatchMixer	0.844 $\pm$ 0.052	0.873 $\pm$ 0.039	0.782 $\pm$ 0.060	0.875 $\pm$ 0.037	0.959 $\pm$ 0.015	0.914 $\pm$ 0.075	0.932 $\pm$ 0.119
	DLinear	0.852 $\pm$ 0.033	0.847 $\pm$ 0.044	0.745 $\pm$ 0.064	0.848 $\pm$ 0.044	0.957 $\pm$ 0.010	0.852 $\pm$ 0.095	1.015 $\pm$ 0.146
	TSMixer	0.462 $\pm$ 0.274	0.597 $\pm$ 0.252	0.459 $\pm$ 0.274	0.650 $\pm$ 0.207	0.825 $\pm$ 0.131	0.971 $\pm$ 0.058	0.474 $\pm$ 0.268
	FRets	0.645 $\pm$ 0.142	0.763 $\pm$ 0.111	0.631 $\pm$ 0.137	0.781 $\pm$ 0.096	0.896 $\pm$ 0.062	0.964 $\pm$ 0.032	0.670 $\pm$ 0.143
	<i>flat-value persistence</i>	0.786 $\pm$ 0.044	0.875 $\pm$ 0.027	0.785 $\pm$ 0.044	0.882 $\pm$ 0.025	0.957 $\pm$ 0.010	0.997 $\pm$ 0.001	0.789 $\pm$ 0.044
	<i>occurrence-persistence</i>	0.854 $\pm$ 0.033	0.853 $\pm$ 0.029	0.752 $\pm$ 0.045	0.853 $\pm$ 0.029	0.957 $\pm$ 0.011	0.857 $\pm$ 0.028	1.002 $\pm$ 0.018
per-day	SegRNN	0.775 $\pm$ 0.108	0.863 $\pm$ 0.062	0.769 $\pm$ 0.096	0.872 $\pm$ 0.055	0.976	0.992 $\pm$ 0.021	0.782 $\pm$ 0.124
	xPatch	0.795 $\pm$ 0.108	0.851 $\pm$ 0.061	0.751 $\pm$ 0.092	0.856 $\pm$ 0.059	0.947 $\pm$ 0.040	0.934 $\pm$ 0.081	0.859 $\pm$ 0.156
	iTransformer	0.784 $\pm$ 0.125	0.850 $\pm$ 0.085	0.751 $\pm$ 0.122	0.855 $\pm$ 0.081	0.939 $\pm$ 0.045	0.943 $\pm$ 0.049	0.833 $\pm$ 0.123
	PatchTST	0.770 $\pm$ 0.136	0.828 $\pm$ 0.081	0.720 $\pm$ 0.115	0.834 $\pm$ 0.075	0.931 $\pm$ 0.047	0.917 $\pm$ 0.044	0.844 $\pm$ 0.164
	TiDE	0.826 $\pm$ 0.080	0.866 $\pm$ 0.053	0.773 $\pm$ 0.083	0.868 $\pm$ 0.053	0.952 $\pm$ 0.024	0.922 $\pm$ 0.060	0.900 $\pm$ 0.102
	RLinear	0.809 $\pm$ 0.096	0.855 $\pm$ 0.064	0.756 $\pm$ 0.094	0.857 $\pm$ 0.063	0.946 $\pm$ 0.032	0.918 $\pm$ 0.068	0.885 $\pm$ 0.117
	PatchMixer	0.854 $\pm$ 0.063	0.877 $\pm$ 0.038	0.789 $\pm$ 0.060	0.878 $\pm$ 0.037	0.960 $\pm$ 0.019	0.910 $\pm$ 0.054	0.945 $\pm$ 0.103
	DLinear	0.860 $\pm$ 0.051	0.849 $\pm$ 0.048	0.748 $\pm$ 0.065	0.851 $\pm$ 0.047	0.959 $\pm$ 0.018	0.848 $\pm$ 0.084	1.029 $\pm$ 0.129
	TSMixer	0.453 $\pm$ 0.268	0.584 $\pm$ 0.263	0.447 $\pm$ 0.272	0.634 $\pm$ 0.219	0.725 $\pm$ 0.157	0.946 $\pm$ 0.102	0.476 $\pm$ 0.252
	FRets	0.631 $\pm$ 0.161	0.739 $\pm$ 0.135	0.603 $\pm$ 0.158	0.755 $\pm$ 0.124	0.866 $\pm$ 0.148	0.922 $\pm$ 0.100	0.685 $\pm$ 0.158
	<i>flat-value persistence</i>	0.781 $\pm$ 0.122	0.868 $\pm$ 0.078	0.778 $\pm$ 0.125	0.876 $\pm$ 0.071	0.932	0.993 $\pm$ 0.018	0.787 $\pm$ 0.120
	<i>occurrence-persistence</i>	0.850 $\pm$ 0.088	0.850 $\pm$ 0.053	0.750 $\pm$ 0.076	0.851 $\pm$ 0.052	0.955 $\pm$ 0.032	0.860 $\pm$ 0.045	0.995 $\pm$ 0.117

Table S9 Verification panel — Proton SPE (6 h). Event skill at a 1-day historical horizon and a 6 h forecast horizon, on the univariate track binarized at the proton ≥ 10 pfu solar-proton-event threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.108 $\pm$ 0.057	0.183 $\pm$ 0.085	0.103 $\pm$ 0.052	0.276 $\pm$ 0.067	0.571 $\pm$ 0.048	0.751 $\pm$ 0.101	0.148 $\pm$ 0.087
	xPatch	0.071 $\pm$ 0.077	0.116 $\pm$ 0.114	0.065 $\pm$ 0.067	0.178 $\pm$ 0.098	0.474 $\pm$ 0.085	0.567 $\pm$ 0.151	0.141 $\pm$ 0.157
	iTransformer	0.119 $\pm$ 0.098	0.182 $\pm$ 0.129	0.104 $\pm$ 0.080	0.237 $\pm$ 0.100	0.533 $\pm$ 0.087	0.549 $\pm$ 0.097	0.228 $\pm$ 0.194
	PatchTST	0.088 $\pm$ 0.111	0.133 $\pm$ 0.150	0.076 $\pm$ 0.090	0.190 $\pm$ 0.120	0.503 $\pm$ 0.095	0.641 $\pm$ 0.295	0.180 $\pm$ 0.230
	TiDE	0.119 $\pm$ 0.094	0.187 $\pm$ 0.122	0.107 $\pm$ 0.077	0.257 $\pm$ 0.083	0.556 $\pm$ 0.073	0.645 $\pm$ 0.182	0.209 $\pm$ 0.191
	RLinear	0.113 $\pm$ 0.096	0.177 $\pm$ 0.125	0.101 $\pm$ 0.078	0.248 $\pm$ 0.086	0.550 $\pm$ 0.075	0.655 $\pm$ 0.212	0.199 $\pm$ 0.194
	PatchMixer	0.090 $\pm$ 0.116	0.137 $\pm$ 0.159	0.079 $\pm$ 0.097	0.191 $\pm$ 0.139	0.486 $\pm$ 0.138	0.558 $\pm$ 0.234	0.178 $\pm$ 0.221
	DLinear	0.167 $\pm$ 0.126	0.171 $\pm$ 0.100	0.099 $\pm$ 0.063	0.177 $\pm$ 0.103	0.492 $\pm$ 0.124	0.204 $\pm$ 0.120	0.885 $\pm$ 0.493
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.046 $\pm$ 0.078	0.070 $\pm$ 0.120	0.040 $\pm$ 0.068	0.088 $\pm$ 0.140	0.277 $\pm$ 0.267	0.210 $\pm$ 0.225	0.121 $\pm$ 0.187
	<i>flat-value persistence</i>	0.203 $\pm$ 0.086	0.203 $\pm$ 0.086	0.118 $\pm$ 0.054	0.203 $\pm$ 0.086	0.535 $\pm$ 0.097	0.209 $\pm$ 0.086	1.000 $\pm$ 0.012
per-window	SegRNN	0.098 $\pm$ 0.029	0.167 $\pm$ 0.045	0.098 $\pm$ 0.029	0.292 $\pm$ 0.045	0.542 $\pm$ 0.045	0.943 $\pm$ 0.016	0.105 $\pm$ 0.029
	xPatch	0.094 $\pm$ 0.049	0.158 $\pm$ 0.077	0.094 $\pm$ 0.048	0.271 $\pm$ 0.080	0.488 $\pm$ 0.077	0.864 $\pm$ 0.053	0.109 $\pm$ 0.052
	iTransformer	0.086 $\pm$ 0.035	0.146 $\pm$ 0.055	0.086 $\pm$ 0.035	0.265 $\pm$ 0.058	0.496 $\pm$ 0.063	0.895 $\pm$ 0.051	0.096 $\pm$ 0.037
	PatchTST	0.063 $\pm$ 0.048	0.107 $\pm$ 0.077	0.062 $\pm$ 0.048	0.221 $\pm$ 0.081	0.480 $\pm$ 0.082	0.915 $\pm$ 0.068	0.069 $\pm$ 0.056
	TiDE	0.110 $\pm$ 0.040	0.184 $\pm$ 0.061	0.110 $\pm$ 0.040	0.308 $\pm$ 0.056	0.552 $\pm$ 0.047	0.942 $\pm$ 0.014	0.118 $\pm$ 0.043
	RLinear	0.098 $\pm$ 0.040	0.166 $\pm$ 0.063	0.098 $\pm$ 0.040	0.291 $\pm$ 0.059	0.548 $\pm$ 0.049	0.951 $\pm$ 0.024	0.104 $\pm$ 0.044
	PatchMixer	0.100 $\pm$ 0.053	0.169 $\pm$ 0.081	0.100 $\pm$ 0.052	0.290 $\pm$ 0.077	0.531 $\pm$ 0.067	0.929 $\pm$ 0.030	0.109 $\pm$ 0.057
	DLinear	0.200 $\pm$ 0.081	0.283 $\pm$ 0.085	0.185 $\pm$ 0.069	0.334 $\pm$ 0.069	0.514 $\pm$ 0.065	0.634 $\pm$ 0.130	0.340 $\pm$ 0.151
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.036 $\pm$ 0.055	0.063 $\pm$ 0.093	0.036 $\pm$ 0.054	0.122 $\pm$ 0.153	0.286 $\pm$ 0.249	0.569 $\pm$ 0.366	0.049 $\pm$ 0.070
	<i>flat-value persistence</i>	0.106 $\pm$ 0.027	0.178 $\pm$ 0.041	0.106 $\pm$ 0.027	0.299 $\pm$ 0.042	0.530 $\pm$ 0.044	0.914 $\pm$ 0.024	0.116 $\pm$ 0.026
	<i>occurrence-persistence</i>	0.381 $\pm$ 0.062	0.381 $\pm$ 0.062	0.271 $\pm$ 0.055	0.381 $\pm$ 0.062	0.607 $\pm$ 0.056	0.424 $\pm$ 0.068	1.002 $\pm$ 0.014
per-day	SegRNN	0.125 $\pm$ 0.038	0.209 $\pm$ 0.059	0.125 $\pm$ 0.038	0.341 $\pm$ 0.055		1.000 $\pm$ 0.000	0.125 $\pm$ 0.038
	xPatch	0.118 $\pm$ 0.031	0.196 $\pm$ 0.049	0.117 $\pm$ 0.031	0.309 $\pm$ 0.068	0.481 $\pm$ 0.069	0.873 $\pm$ 0.176	0.137 $\pm$ 0.025
	iTransformer	0.104 $\pm$ 0.022	0.176 $\pm$ 0.032	0.104 $\pm$ 0.022	0.304 $\pm$ 0.027	0.518 $\pm$ 0.064	0.962 $\pm$ 0.065	0.109 $\pm$ 0.029
	PatchTST	0.072 $\pm$ 0.044	0.124 $\pm$ 0.068	0.072 $\pm$ 0.044	0.250 $\pm$ 0.067	0.541	0.982 $\pm$ 0.051	0.075 $\pm$ 0.051
	TiDE	0.135 $\pm$ 0.040	0.224 $\pm$ 0.061	0.135 $\pm$ 0.040	0.351 $\pm$ 0.061	0.495	0.980 $\pm$ 0.056	0.138 $\pm$ 0.037
	RLinear	0.127 $\pm$ 0.035	0.212 $\pm$ 0.056	0.127 $\pm$ 0.035	0.340 $\pm$ 0.059	0.475	0.978 $\pm$ 0.062	0.130 $\pm$ 0.031
	PatchMixer	0.130 $\pm$ 0.056	0.216 $\pm$ 0.083	0.130 $\pm$ 0.056	0.346 $\pm$ 0.075		1.000 $\pm$ 0.000	0.130 $\pm$ 0.056
	DLinear	0.250 $\pm$ 0.110	0.343 $\pm$ 0.122	0.230 $\pm$ 0.098	0.390 $\pm$ 0.104	0.569 $\pm$ 0.092	0.680 $\pm$ 0.116	0.389 $\pm$ 0.169
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.022 $\pm$ 0.039	0.038 $\pm$ 0.068	0.023 $\pm$ 0.039	0.123 $\pm$ 0.203	0.296	0.476 $\pm$ 0.804	0.041 $\pm$ 0.063
	<i>flat-value persistence</i>	0.133 $\pm$ 0.038	0.221 $\pm$ 0.057	0.133 $\pm$ 0.038	0.351 $\pm$ 0.051		1.000 $\pm$ 0.000	0.133 $\pm$ 0.038
	<i>occurrence-persistence</i>	0.391 $\pm$ 0.048	0.391 $\pm$ 0.075	0.278 $\pm$ 0.065	0.393 $\pm$ 0.075	0.619 $\pm$ 0.050	0.442 $\pm$ 0.126	1.017 $\pm$ 0.296

Table S10 Verification panel — XRS M-class (6 h). Event skill at a 1-day historical horizon and a 6 h forecast horizon, on the univariate track binarized at the M-class ($\geq 10^{-5}$ W m $^{-2}$) threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.023 $\pm$ 0.015	0.045 $\pm$ 0.027	0.023 $\pm$ 0.015	0.128 $\pm$ 0.054	0.542 $\pm$ 0.062	0.739 $\pm$ 0.152	0.031 $\pm$ 0.017
	xPatch	0.007 $\pm$ 0.007	0.013 $\pm$ 0.014	0.007 $\pm$ 0.007	0.076 $\pm$ 0.021	0.496 $\pm$ 0.008	0.825 $\pm$ 0.223	0.009 $\pm$ 0.012
	iTransformer	0.008 $\pm$ 0.004	0.016 $\pm$ 0.009	0.008 $\pm$ 0.005	0.055 $\pm$ 0.034	0.437 $\pm$ 0.066	0.405 $\pm$ 0.317	0.021 $\pm$ 0.014
	PatchTST	0.001 $\pm$ 0.002	0.002 $\pm$ 0.004	0.001 $\pm$ 0.002	0.032	0.374	0.263	0.003 $\pm$ 0.008
	TiDE	0.017 $\pm$ 0.007	0.034 $\pm$ 0.013	0.017 $\pm$ 0.007	0.122 $\pm$ 0.027	0.550 $\pm$ 0.033	0.858 $\pm$ 0.077	0.020 $\pm$ 0.007
	RLinear	0.010 $\pm$ 0.007	0.020 $\pm$ 0.013	0.010 $\pm$ 0.007	0.095 $\pm$ 0.033	0.552 $\pm$ 0.125	0.968 $\pm$ 0.078	0.010 $\pm$ 0.007
	PatchMixer	0.007 $\pm$ 0.009	0.014 $\pm$ 0.017	0.007 $\pm$ 0.009	0.060 $\pm$ 0.053	0.409 $\pm$ 0.214	0.609 $\pm$ 0.445	0.033 $\pm$ 0.059
	DLinear	0.019 $\pm$ 0.007	0.035 $\pm$ 0.012	0.018 $\pm$ 0.006	0.080 $\pm$ 0.037	0.480 $\pm$ 0.046	0.387 $\pm$ 0.292	0.075 $\pm$ 0.074
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000		0.000	0.005 $\pm$ 0.014
	<i>flat-value persistence</i>	0.049 $\pm$ 0.020	0.048 $\pm$ 0.019	0.025 $\pm$ 0.010	0.048 $\pm$ 0.019	0.454 $\pm$ 0.051	0.048 $\pm$ 0.019	1.011 $\pm$ 0.110
per-window	SegRNN	0.038 $\pm$ 0.023	0.071 $\pm$ 0.041	0.037 $\pm$ 0.022	0.169 $\pm$ 0.046	0.507 $\pm$ 0.061	0.827 $\pm$ 0.151	0.048 $\pm$ 0.032
	xPatch	0.018 $\pm$ 0.017	0.034 $\pm$ 0.032	0.018 $\pm$ 0.017	0.131 $\pm$ 0.043	0.478 $\pm$ 0.065	0.826 $\pm$ 0.270	0.024 $\pm$ 0.025
	iTransformer	0.017 $\pm$ 0.008	0.033 $\pm$ 0.016	0.017 $\pm$ 0.008	0.088 $\pm$ 0.040	0.383 $\pm$ 0.072	0.468 $\pm$ 0.212	0.037 $\pm$ 0.011
	PatchTST	0.002 $\pm$ 0.006	0.004 $\pm$ 0.012	0.002 $\pm$ 0.006	0.063	0.319	0.362	0.006 $\pm$ 0.018
	TiDE	0.040 $\pm$ 0.015	0.076 $\pm$ 0.027	0.039 $\pm$ 0.014	0.185 $\pm$ 0.041	0.532 $\pm$ 0.053	0.876 $\pm$ 0.089	0.045 $\pm$ 0.012
	RLinear	0.024 $\pm$ 0.012	0.046 $\pm$ 0.023	0.024 $\pm$ 0.012	0.150 $\pm$ 0.037	0.534 $\pm$ 0.115	0.979 $\pm$ 0.040	0.025 $\pm$ 0.013
	PatchMixer	0.020 $\pm$ 0.021	0.038 $\pm$ 0.039	0.019 $\pm$ 0.020	0.111 $\pm$ 0.087	0.402 $\pm$ 0.214	0.676 $\pm$ 0.452	0.030 $\pm$ 0.019
	DLinear	0.042 $\pm$ 0.010	0.078 $\pm$ 0.018	0.041 $\pm$ 0.010	0.166 $\pm$ 0.042	0.489 $\pm$ 0.055	0.674 $\pm$ 0.238	0.066 $\pm$ 0.025
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	-0.001		0.000	0.014 $\pm$ 0.038
	<i>flat-value persistence</i>	0.049 $\pm$ 0.019	0.092 $\pm$ 0.033	0.048 $\pm$ 0.019	0.194 $\pm$ 0.042	0.520 $\pm$ 0.041	0.780 $\pm$ 0.053	0.062 $\pm$ 0.019
	<i>occurrence-persistence</i>	0.120 $\pm$ 0.102	0.119 $\pm$ 0.102	0.068 $\pm$ 0.059	0.119 $\pm$ 0.102	0.421 $\pm$ 0.176	0.124 $\pm$ 0.103	1.014 $\pm$ 0.082
per-day	SegRNN	0.125 $\pm$ 0.148	0.205 $\pm$ 0.240	0.125 $\pm$ 0.148	0.453 $\pm$ 0.090		1.000 $\pm$ 0.000	0.125 $\pm$ 0.148
	xPatch	0.038 $\pm$ 0.066	0.068 $\pm$ 0.118	0.038 $\pm$ 0.066	0.303 $\pm$ 0.079		1.000 $\pm$ 0.000	0.038 $\pm$ 0.066
	iTransformer	0.038 $\pm$ 0.066	0.068 $\pm$ 0.118	0.038 $\pm$ 0.066	0.303 $\pm$ 0.079		1.000 $\pm$ 0.000	0.038 $\pm$ 0.066
	PatchTST	0.015 $\pm$ 0.043	0.028 $\pm$ 0.078	0.015 $\pm$ 0.043	0.275		1.000	0.015 $\pm$ 0.043
	TiDE	0.053 $\pm$ 0.092	0.093 $\pm$ 0.160	0.053 $\pm$ 0.092	0.361 $\pm$ 0.081		1.000 $\pm$ 0.000	0.053 $\pm$ 0.092
	RLinear	0.053 $\pm$ 0.092	0.093 $\pm$ 0.160	0.053 $\pm$ 0.092	0.361 $\pm$ 0.081		1.000 $\pm$ 0.000	0.053 $\pm$ 0.092
	PatchMixer	0.038 $\pm$ 0.066	0.068 $\pm$ 0.118	0.038 $\pm$ 0.066	0.303 $\pm$ 0.079		1.000 $\pm$ 0.000	0.038 $\pm$ 0.066
	DLinear	0.075 $\pm$ 0.131	0.125 $\pm$ 0.217	0.075 $\pm$ 0.131	0.430 $\pm$ 0.111		1.000 $\pm$ 0.000	0.075 $\pm$ 0.131
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	<i>flat-value persistence</i>	0.125 $\pm$ 0.148	0.205 $\pm$ 0.240	0.125 $\pm$ 0.148	0.453 $\pm$ 0.090		1.000 $\pm$ 0.000	0.125 $\pm$ 0.148
	<i>occurrence-persistence</i>	0.234 $\pm$ 0.303	0.256 $\pm$ 0.338	0.173 $\pm$ 0.233	0.264 $\pm$ 0.351	0.737 $\pm$ 0.176	0.318 $\pm$ 0.455	0.926 $\pm$ 0.400

Table S11 Verification panel — XRS X-class (6 h). Event skill at a 1-day historical horizon and a 6 h forecast horizon, on the univariate track binarized at the X-class ($\geq 10^{-4}$ W m $^{-2}$) threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.815 $\pm$ 0.046	0.846 $\pm$ 0.033	0.740 $\pm$ 0.050	0.847 $\pm$ 0.032	0.947 $\pm$ 0.016	0.885 $\pm$ 0.024	0.924 $\pm$ 0.040
	xPatch	0.785 $\pm$ 0.090	0.800 $\pm$ 0.078	0.677 $\pm$ 0.107	0.801 $\pm$ 0.078	0.932 $\pm$ 0.036	0.823 $\pm$ 0.093	0.963 $\pm$ 0.118
	iTransformer	0.762 $\pm$ 0.095	0.813 $\pm$ 0.059	0.694 $\pm$ 0.082	0.816 $\pm$ 0.054	0.928 $\pm$ 0.034	0.882 $\pm$ 0.020	0.868 $\pm$ 0.109
	PatchTST	0.738 $\pm$ 0.116	0.768 $\pm$ 0.085	0.635 $\pm$ 0.111	0.770 $\pm$ 0.084	0.912 $\pm$ 0.048	0.811 $\pm$ 0.055	0.914 $\pm$ 0.102
	TiDE	0.778 $\pm$ 0.081	0.800 $\pm$ 0.062	0.676 $\pm$ 0.084	0.801 $\pm$ 0.061	0.930 $\pm$ 0.033	0.830 $\pm$ 0.043	0.942 $\pm$ 0.064
	RLinear	0.788 $\pm$ 0.081	0.803 $\pm$ 0.062	0.680 $\pm$ 0.084	0.803 $\pm$ 0.061	0.933 $\pm$ 0.033	0.825 $\pm$ 0.046	0.960 $\pm$ 0.070
	PatchMixer	0.767 $\pm$ 0.109	0.794 $\pm$ 0.067	0.669 $\pm$ 0.092	0.796 $\pm$ 0.064	0.926 $\pm$ 0.041	0.834 $\pm$ 0.028	0.925 $\pm$ 0.124
	DLinear	0.824 $\pm$ 0.060	0.776 $\pm$ 0.065	0.645 $\pm$ 0.084	0.778 $\pm$ 0.062	0.943 $\pm$ 0.024	0.741 $\pm$ 0.083	1.130 $\pm$ 0.133
	TSMixer	0.378 $\pm$ 0.293	0.498 $\pm$ 0.240	0.358 $\pm$ 0.248	0.569 $\pm$ 0.184	0.801 $\pm$ 0.093	0.946 $\pm$ 0.072	0.414 $\pm$ 0.364
	FReTS	0.416 $\pm$ 0.158	0.559 $\pm$ 0.154	0.403 $\pm$ 0.143	0.614 $\pm$ 0.112	0.806 $\pm$ 0.051	0.947 $\pm$ 0.057	0.445 $\pm$ 0.191
	<i>flat-value persistence</i>	0.835 $\pm$ 0.051	0.831 $\pm$ 0.042	0.719 $\pm$ 0.060	0.831 $\pm$ 0.042	0.951 $\pm$ 0.018	0.832 $\pm$ 0.034	1.010 $\pm$ 0.026
per-window	SegRNN	0.682 $\pm$ 0.041	0.803 $\pm$ 0.030	0.680 $\pm$ 0.042	0.818 $\pm$ 0.026	0.929 $\pm$ 0.016	0.995 $\pm$ 0.008	0.686 $\pm$ 0.040
	xPatch	0.677 $\pm$ 0.104	0.781 $\pm$ 0.072	0.654 $\pm$ 0.097	0.795 $\pm$ 0.064	0.904 $\pm$ 0.039	0.948 $\pm$ 0.040	0.716 $\pm$ 0.117
	iTransformer	0.638 $\pm$ 0.094	0.766 $\pm$ 0.073	0.632 $\pm$ 0.093	0.786 $\pm$ 0.059	0.906 $\pm$ 0.026	0.987 $\pm$ 0.010	0.647 $\pm$ 0.097
	PatchTST	0.671 $\pm$ 0.076	0.775 $\pm$ 0.062	0.644 $\pm$ 0.082	0.787 $\pm$ 0.057	0.898 $\pm$ 0.033	0.935 $\pm$ 0.033	0.719 $\pm$ 0.062
	TiDE	0.728 $\pm$ 0.047	0.815 $\pm$ 0.041	0.697 $\pm$ 0.058	0.822 $\pm$ 0.040	0.921 $\pm$ 0.022	0.940 $\pm$ 0.050	0.777 $\pm$ 0.056
	RLinear	0.731 $\pm$ 0.054	0.816 $\pm$ 0.047	0.699 $\pm$ 0.067	0.822 $\pm$ 0.046	0.921 $\pm$ 0.024	0.937 $\pm$ 0.051	0.783 $\pm$ 0.055
	PatchMixer	0.780 $\pm$ 0.064	0.818 $\pm$ 0.042	0.702 $\pm$ 0.061	0.821 $\pm$ 0.042	0.932 $\pm$ 0.021	0.874 $\pm$ 0.083	0.903 $\pm$ 0.132
	DLinear	0.762 $\pm$ 0.053	0.798 $\pm$ 0.067	0.677 $\pm$ 0.088	0.801 $\pm$ 0.067	0.924 $\pm$ 0.020	0.855 $\pm$ 0.133	0.912 $\pm$ 0.182
	TSMixer	0.481 $\pm$ 0.321	0.594 $\pm$ 0.276	0.460 $\pm$ 0.286	0.648 $\pm$ 0.214	0.878 $\pm$ 0.068	0.961 $\pm$ 0.065	0.515 $\pm$ 0.378
	FReTS	0.577 $\pm$ 0.166	0.691 $\pm$ 0.118	0.544 $\pm$ 0.131	0.718 $\pm$ 0.087	0.872 $\pm$ 0.036	0.927 $\pm$ 0.093	0.635 $\pm$ 0.241
	<i>flat-value persistence</i>	0.690 $\pm$ 0.056	0.808 $\pm$ 0.039	0.688 $\pm$ 0.056	0.824 $\pm$ 0.033	0.933 $\pm$ 0.015	0.998 $\pm$ 0.001	0.691 $\pm$ 0.056
	<i>occurrence-persistence</i>	0.759 $\pm$ 0.060	0.756 $\pm$ 0.054	0.622 $\pm$ 0.070	0.756 $\pm$ 0.054	0.914 $\pm$ 0.028	0.762 $\pm$ 0.049	1.008 $\pm$ 0.025
per-day	SegRNN	0.650 $\pm$ 0.144	0.774 $\pm$ 0.109	0.646 $\pm$ 0.138	0.795 $\pm$ 0.089	0.941	0.993 $\pm$ 0.020	0.656 $\pm$ 0.154
	xPatch	0.653 $\pm$ 0.099	0.758 $\pm$ 0.069	0.623 $\pm$ 0.091	0.771 $\pm$ 0.061	0.890 $\pm$ 0.040	0.927 $\pm$ 0.039	0.707 $\pm$ 0.112
	iTransformer	0.622 $\pm$ 0.128	0.751 $\pm$ 0.104	0.615 $\pm$ 0.126	0.774 $\pm$ 0.084	0.895 $\pm$ 0.049	0.984 $\pm$ 0.027	0.632 $\pm$ 0.133
	PatchTST	0.657 $\pm$ 0.089	0.756 $\pm$ 0.085	0.623 $\pm$ 0.108	0.767 $\pm$ 0.083	0.887 $\pm$ 0.049	0.910 $\pm$ 0.075	0.724 $\pm$ 0.050
	TiDE	0.721 $\pm$ 0.100	0.797 $\pm$ 0.075	0.674 $\pm$ 0.099	0.804 $\pm$ 0.073	0.913 $\pm$ 0.046	0.910 $\pm$ 0.079	0.797 $\pm$ 0.130
	RLinear	0.717 $\pm$ 0.092	0.792 $\pm$ 0.077	0.668 $\pm$ 0.102	0.799 $\pm$ 0.075	0.911 $\pm$ 0.044	0.903 $\pm$ 0.092	0.800 $\pm$ 0.128
	PatchMixer	0.752 $\pm$ 0.127	0.787 $\pm$ 0.059	0.661 $\pm$ 0.081	0.792 $\pm$ 0.051	0.919 $\pm$ 0.044	0.850 $\pm$ 0.077	0.901 $\pm$ 0.216
	DLinear	0.732 $\pm$ 0.091	0.761 $\pm$ 0.099	0.631 $\pm$ 0.127	0.763 $\pm$ 0.097	0.906 $\pm$ 0.043	0.810 $\pm$ 0.143	0.928 $\pm$ 0.206
	TSMixer	0.481 $\pm$ 0.291	0.606 $\pm$ 0.248	0.468 $\pm$ 0.268	0.659 $\pm$ 0.192	0.917 $\pm$ 0.031	0.973 $\pm$ 0.046	0.503 $\pm$ 0.328
	FReTS	0.576 $\pm$ 0.186	0.688 $\pm$ 0.124	0.542 $\pm$ 0.141	0.717 $\pm$ 0.093	0.877 $\pm$ 0.081	0.931 $\pm$ 0.106	0.635 $\pm$ 0.279
	<i>flat-value persistence</i>	0.664 $\pm$ 0.126	0.785 $\pm$ 0.089	0.660 $\pm$ 0.118	0.804 $\pm$ 0.074	0.949	0.993 $\pm$ 0.019	0.670 $\pm$ 0.139
	<i>occurrence-persistence</i>	0.744 $\pm$ 0.103	0.731 $\pm$ 0.088	0.593 $\pm$ 0.106	0.732 $\pm$ 0.088	0.903 $\pm$ 0.053	0.730 $\pm$ 0.079	1.034 $\pm$ 0.093

Table S12 Verification panel — Proton SPE (12 h). Event skill at a 1-day historical horizon and a 12 h forecast horizon, on the univariate track binarized at the proton ≥ 10 pfu solar-proton-event threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.055 $\pm$ 0.037	0.098 $\pm$ 0.062	0.053 $\pm$ 0.035	0.189 $\pm$ 0.054	0.496 $\pm$ 0.034	0.735 $\pm$ 0.142	0.081 $\pm$ 0.067
	xPatch	0.059 $\pm$ 0.085	0.094 $\pm$ 0.117	0.052 $\pm$ 0.069	0.159 $\pm$ 0.089	0.469 $\pm$ 0.073	0.668 $\pm$ 0.241	0.124 $\pm$ 0.209
	iTransformer	0.079 $\pm$ 0.086	0.125 $\pm$ 0.122	0.070 $\pm$ 0.072	0.175 $\pm$ 0.108	0.465 $\pm$ 0.108	0.475 $\pm$ 0.052	0.172 $\pm$ 0.184
	PatchTST	0.069 $\pm$ 0.098	0.105 $\pm$ 0.133	0.060 $\pm$ 0.079	0.141 $\pm$ 0.129	0.417 $\pm$ 0.147	0.378 $\pm$ 0.101	0.171 $\pm$ 0.216
	TiDE	0.085 $\pm$ 0.089	0.133 $\pm$ 0.120	0.075 $\pm$ 0.072	0.196 $\pm$ 0.089	0.497 $\pm$ 0.085	0.585 $\pm$ 0.225	0.175 $\pm$ 0.200
	RLinear	0.082 $\pm$ 0.088	0.128 $\pm$ 0.121	0.072 $\pm$ 0.072	0.191 $\pm$ 0.091	0.493 $\pm$ 0.087	0.590 $\pm$ 0.243	0.169 $\pm$ 0.198
	PatchMixer	0.051 $\pm$ 0.076	0.084 $\pm$ 0.115	0.046 $\pm$ 0.066	0.137 $\pm$ 0.107	0.429 $\pm$ 0.105	0.555 $\pm$ 0.190	0.106 $\pm$ 0.162
	DLinear	0.118 $\pm$ 0.118	0.124 $\pm$ 0.086	0.071 $\pm$ 0.053	0.136 $\pm$ 0.082	0.432 $\pm$ 0.116	0.189 $\pm$ 0.105	0.726 $\pm$ 0.664
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.002 $\pm$ 0.002	0.004 $\pm$ 0.004	0.002 $\pm$ 0.002	0.020 $\pm$ 0.012	0.247 $\pm$ 0.065	0.412 $\pm$ 0.399	0.008 $\pm$ 0.009
	<i>flat-value persistence</i>	0.146 $\pm$ 0.077	0.147 $\pm$ 0.077	0.084 $\pm$ 0.046	0.147 $\pm$ 0.077	0.455 $\pm$ 0.106	0.154 $\pm$ 0.077	0.989 $\pm$ 0.046
per-window	SegRNN	0.061 $\pm$ 0.018	0.102 $\pm$ 0.029	0.061 $\pm$ 0.018	0.226 $\pm$ 0.036	0.491 $\pm$ 0.052	0.962 $\pm$ 0.019	0.063 $\pm$ 0.018
	xPatch	0.057 $\pm$ 0.036	0.095 $\pm$ 0.057	0.057 $\pm$ 0.037	0.207 $\pm$ 0.062	0.431 $\pm$ 0.068	0.898 $\pm$ 0.062	0.065 $\pm$ 0.044
	iTransformer	0.052 $\pm$ 0.021	0.087 $\pm$ 0.034	0.052 $\pm$ 0.021	0.203 $\pm$ 0.046	0.438 $\pm$ 0.062	0.922 $\pm$ 0.047	0.056 $\pm$ 0.022
	PatchTST	0.039 $\pm$ 0.028	0.066 $\pm$ 0.046	0.039 $\pm$ 0.027	0.170 $\pm$ 0.069	0.403 $\pm$ 0.109	0.894 $\pm$ 0.085	0.043 $\pm$ 0.028
	TiDE	0.073 $\pm$ 0.032	0.122 $\pm$ 0.051	0.074 $\pm$ 0.032	0.247 $\pm$ 0.055	0.497 $\pm$ 0.059	0.954 $\pm$ 0.022	0.078 $\pm$ 0.033
	RLinear	0.067 $\pm$ 0.031	0.111 $\pm$ 0.049	0.067 $\pm$ 0.031	0.235 $\pm$ 0.056	0.493 $\pm$ 0.064	0.958 $\pm$ 0.028	0.070 $\pm$ 0.032
	PatchMixer	0.058 $\pm$ 0.037	0.096 $\pm$ 0.058	0.058 $\pm$ 0.037	0.214 $\pm$ 0.068	0.463 $\pm$ 0.058	0.943 $\pm$ 0.034	0.061 $\pm$ 0.038
	DLinear	0.146 $\pm$ 0.102	0.216 $\pm$ 0.125	0.144 $\pm$ 0.098	0.301 $\pm$ 0.096	0.474 $\pm$ 0.075	0.772 $\pm$ 0.103	0.204 $\pm$ 0.155
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.006 $\pm$ 0.004	0.010 $\pm$ 0.007	0.006 $\pm$ 0.004	0.058 $\pm$ 0.025	0.243 $\pm$ 0.089	0.808 $\pm$ 0.193	0.008 $\pm$ 0.007
	<i>flat-value persistence</i>	0.069 $\pm$ 0.020	0.115 $\pm$ 0.031	0.069 $\pm$ 0.020	0.238 $\pm$ 0.036	0.478 $\pm$ 0.042	0.940 $\pm$ 0.019	0.073 $\pm$ 0.019
	<i>occurrence-persistence</i>	0.448 $\pm$ 0.073	0.448 $\pm$ 0.071	0.344 $\pm$ 0.074	0.448 $\pm$ 0.071	0.652 $\pm$ 0.061	0.511 $\pm$ 0.078	0.996 $\pm$ 0.027
per-day	SegRNN	0.057 $\pm$ 0.027	0.096 $\pm$ 0.039	0.057 $\pm$ 0.027	0.222 $\pm$ 0.046		1.000 $\pm$ 0.000	0.057 $\pm$ 0.027
	xPatch	0.058 $\pm$ 0.037	0.096 $\pm$ 0.057	0.058 $\pm$ 0.037	0.214 $\pm$ 0.068	0.459 $\pm$ 0.026	0.962 $\pm$ 0.066	0.062 $\pm$ 0.042
	iTransformer	0.053 $\pm$ 0.020	0.090 $\pm$ 0.032	0.054 $\pm$ 0.020	0.202 $\pm$ 0.064	0.331 $\pm$ 0.126	0.880 $\pm$ 0.222	0.061 $\pm$ 0.010
	PatchTST	0.033 $\pm$ 0.023	0.056 $\pm$ 0.039	0.033 $\pm$ 0.023	0.158 $\pm$ 0.077	0.204	0.900 $\pm$ 0.278	0.036 $\pm$ 0.019
	TiDE	0.068 $\pm$ 0.031	0.113 $\pm$ 0.045	0.068 $\pm$ 0.031	0.243 $\pm$ 0.050		1.000 $\pm$ 0.000	0.068 $\pm$ 0.031
	RLinear	0.060 $\pm$ 0.028	0.101 $\pm$ 0.039	0.060 $\pm$ 0.028	0.229 $\pm$ 0.045		1.000 $\pm$ 0.000	0.060 $\pm$ 0.028
	PatchMixer	0.063 $\pm$ 0.034	0.105 $\pm$ 0.052	0.063 $\pm$ 0.034	0.232 $\pm$ 0.061		1.000 $\pm$ 0.000	0.063 $\pm$ 0.034
	DLinear	0.151 $\pm$ 0.133	0.217 $\pm$ 0.159	0.148 $\pm$ 0.127	0.291 $\pm$ 0.133	0.454 $\pm$ 0.116	0.721 $\pm$ 0.119	0.221 $\pm$ 0.186
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.003 $\pm$ 0.007	0.006 $\pm$ 0.012	0.004 $\pm$ 0.007	0.054 $\pm$ 0.097		0.667 $\pm$ 0.925	0.008 $\pm$ 0.012
	<i>flat-value persistence</i>	0.067 $\pm$ 0.023	0.112 $\pm$ 0.032	0.067 $\pm$ 0.022	0.238 $\pm$ 0.043	0.408	0.967 $\pm$ 0.093	0.070 $\pm$ 0.021
	<i>occurrence-persistence</i>	0.456 $\pm$ 0.070	0.462 $\pm$ 0.075	0.354 $\pm$ 0.074	0.462 $\pm$ 0.074	0.662 $\pm$ 0.059	0.531 $\pm$ 0.092	0.976 $\pm$ 0.140

Table S13 Verification panel — XRS M-class (12 h). Event skill at a 1-day historical horizon and a 12 h forecast horizon, on the univariate track binarized at the M-class ($\geq 10^{-5}$ W m $^{-2}$) threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.011 $\pm$ 0.007	0.022 $\pm$ 0.014	0.011 $\pm$ 0.007	0.092 $\pm$ 0.035	0.509 $\pm$ 0.046	0.800 $\pm$ 0.122	0.015 $\pm$ 0.010
	xPatch	0.005 $\pm$ 0.003	0.009 $\pm$ 0.006	0.005 $\pm$ 0.003	0.042 $\pm$ 0.024	0.408 $\pm$ 0.064	0.411 $\pm$ 0.255	0.012 $\pm$ 0.007
	iTransformer	0.001 $\pm$ 0.002	0.002 $\pm$ 0.005	0.001 $\pm$ 0.002	0.026 $\pm$ 0.049	0.319 $\pm$ 0.230	0.380 $\pm$ 0.649	0.003 $\pm$ 0.003
	PatchTST	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	TiDE	0.009 $\pm$ 0.004	0.018 $\pm$ 0.007	0.009 $\pm$ 0.004	0.088 $\pm$ 0.019	0.515 $\pm$ 0.031	0.866 $\pm$ 0.076	0.010 $\pm$ 0.003
	RLinear	0.006 $\pm$ 0.003	0.011 $\pm$ 0.007	0.006 $\pm$ 0.003	0.072 $\pm$ 0.021	0.510 $\pm$ 0.042	0.957 $\pm$ 0.061	0.006 $\pm$ 0.003
	PatchMixer	0.002 $\pm$ 0.003	0.004 $\pm$ 0.005	0.002 $\pm$ 0.003	0.021 $\pm$ 0.029	0.327 $\pm$ 0.167	0.425 $\pm$ 0.636	0.023 $\pm$ 0.035
	DLinear	0.008 $\pm$ 0.002	0.015 $\pm$ 0.004	0.007 $\pm$ 0.002	0.045 $\pm$ 0.038	0.418 $\pm$ 0.098	0.349 $\pm$ 0.502	0.074 $\pm$ 0.075
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000		0.000 $\pm$ 0.000	0.001 $\pm$ 0.003
	<i>flat-value persistence</i>	0.029 $\pm$ 0.015	0.029 $\pm$ 0.015	0.015 $\pm$ 0.008	0.029 $\pm$ 0.015	0.387 $\pm$ 0.049	0.029 $\pm$ 0.014	1.008 $\pm$ 0.124
per-window	SegRNN	0.021 $\pm$ 0.016	0.041 $\pm$ 0.031	0.021 $\pm$ 0.016	0.127 $\pm$ 0.050	0.442 $\pm$ 0.076	0.831 $\pm$ 0.177	0.027 $\pm$ 0.019
	xPatch	0.012 $\pm$ 0.006	0.023 $\pm$ 0.011	0.012 $\pm$ 0.006	0.072 $\pm$ 0.028	0.330 $\pm$ 0.049	0.457 $\pm$ 0.193	0.028 $\pm$ 0.015
	iTransformer	0.004 $\pm$ 0.009	0.008 $\pm$ 0.017	0.004 $\pm$ 0.009	0.056 $\pm$ 0.089	0.263 $\pm$ 0.287	0.474 $\pm$ 0.630	0.007 $\pm$ 0.010
	PatchTST	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	TiDE	0.022 $\pm$ 0.010	0.043 $\pm$ 0.018	0.022 $\pm$ 0.010	0.138 $\pm$ 0.036	0.476 $\pm$ 0.067	0.883 $\pm$ 0.112	0.025 $\pm$ 0.008
	RLinear	0.014 $\pm$ 0.008	0.028 $\pm$ 0.015	0.014 $\pm$ 0.008	0.115 $\pm$ 0.031	0.480 $\pm$ 0.064	0.971 $\pm$ 0.030	0.015 $\pm$ 0.008
	PatchMixer	0.007 $\pm$ 0.009	0.014 $\pm$ 0.017	0.007 $\pm$ 0.009	0.055 $\pm$ 0.053	0.313 $\pm$ 0.163	0.597 $\pm$ 0.464	0.017 $\pm$ 0.020
	DLinear	0.024 $\pm$ 0.008	0.046 $\pm$ 0.015	0.024 $\pm$ 0.008	0.130 $\pm$ 0.031	0.443 $\pm$ 0.090	0.740 $\pm$ 0.236	0.035 $\pm$ 0.020
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	-0.001 $\pm$ 0.000		0.000 $\pm$ 0.000	0.003 $\pm$ 0.008
	<i>flat-value persistence</i>	0.028 $\pm$ 0.013	0.053 $\pm$ 0.025	0.028 $\pm$ 0.013	0.147 $\pm$ 0.041	0.457 $\pm$ 0.050	0.808 $\pm$ 0.065	0.034 $\pm$ 0.014
	<i>occurrence-persistence</i>	0.200 $\pm$ 0.099	0.204 $\pm$ 0.107	0.121 $\pm$ 0.067	0.205 $\pm$ 0.107	0.515 $\pm$ 0.143	0.219 $\pm$ 0.117	0.983 $\pm$ 0.177
per-day	SegRNN	0.000 $\pm$ 0.001	0.000 $\pm$ 0.001	0.000 $\pm$ 0.000	-0.004		0.000	0.022 $\pm$ 0.062
	xPatch	0.013 $\pm$ 0.036	0.022 $\pm$ 0.064	0.012 $\pm$ 0.034	0.087 $\pm$ 0.253	0.428	0.250 $\pm$ 0.694	0.049 $\pm$ 0.084
	iTransformer	0.000 $\pm$ 0.001	0.000 $\pm$ 0.001	0.000 $\pm$ 0.000	-0.004		0.000	0.022 $\pm$ 0.062
	PatchTST	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	TiDE	0.013 $\pm$ 0.037	0.025 $\pm$ 0.068	0.013 $\pm$ 0.037	0.256		1.000	0.013 $\pm$ 0.037
	RLinear	0.013 $\pm$ 0.037	0.025 $\pm$ 0.068	0.013 $\pm$ 0.037	0.256		1.000	0.013 $\pm$ 0.037
	PatchMixer	0.013 $\pm$ 0.037	0.025 $\pm$ 0.068	0.013 $\pm$ 0.037	0.256		1.000	0.013 $\pm$ 0.037
	DLinear	0.013 $\pm$ 0.037	0.025 $\pm$ 0.068	0.013 $\pm$ 0.037	0.256		1.000	0.013 $\pm$ 0.037
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	<i>flat-value persistence</i>	0.013 $\pm$ 0.037	0.025 $\pm$ 0.068	0.013 $\pm$ 0.037	0.256		1.000	0.013 $\pm$ 0.037
	<i>occurrence-persistence</i>	0.157 $\pm$ 0.162	0.192 $\pm$ 0.184	0.117 $\pm$ 0.113	0.199 $\pm$ 0.187	0.554 $\pm$ 0.129	0.267 $\pm$ 0.224	0.869 $\pm$ 0.744

Table S14 Verification panel — XRS X-class (12 h). Event skill at a 1-day historical horizon and a 12 h forecast horizon, on the univariate track binarized at the X-class ($\geq 10^{-4}$ W m $^{-2}$) threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m \pm c$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.674 $\pm$ 0.098	0.734 $\pm$ 0.071	0.591 $\pm$ 0.089	0.738 $\pm$ 0.067	0.887 $\pm$ 0.042	0.819 $\pm$ 0.032	0.827 $\pm$ 0.095
	xPatch	0.643 $\pm$ 0.123	0.693 $\pm$ 0.097	0.543 $\pm$ 0.114	0.696 $\pm$ 0.094	0.867 $\pm$ 0.059	0.765 $\pm$ 0.059	0.844 $\pm$ 0.102
	iTransformer	0.646 $\pm$ 0.136	0.701 $\pm$ 0.100	0.553 $\pm$ 0.118	0.706 $\pm$ 0.094	0.870 $\pm$ 0.063	0.784 $\pm$ 0.055	0.829 $\pm$ 0.153
	PatchTST	0.629 $\pm$ 0.156	0.661 $\pm$ 0.114	0.509 $\pm$ 0.126	0.663 $\pm$ 0.110	0.854 $\pm$ 0.079	0.713 $\pm$ 0.053	0.887 $\pm$ 0.161
	TiDE	0.578 $\pm$ 0.228	0.609 $\pm$ 0.213	0.464 $\pm$ 0.211	0.611 $\pm$ 0.212	0.815 $\pm$ 0.145	0.658 $\pm$ 0.198	0.881 $\pm$ 0.139
	RLinear	0.583 $\pm$ 0.225	0.610 $\pm$ 0.207	0.465 $\pm$ 0.206	0.612 $\pm$ 0.206	0.817 $\pm$ 0.141	0.656 $\pm$ 0.189	0.890 $\pm$ 0.141
	PatchMixer	0.613 $\pm$ 0.159	0.658 $\pm$ 0.127	0.507 $\pm$ 0.138	0.662 $\pm$ 0.123	0.847 $\pm$ 0.085	0.728 $\pm$ 0.086	0.845 $\pm$ 0.149
	DLinear	0.701 $\pm$ 0.148	0.649 $\pm$ 0.133	0.500 $\pm$ 0.142	0.652 $\pm$ 0.134	0.880 $\pm$ 0.079	0.614 $\pm$ 0.125	1.166 $\pm$ 0.116
	TSMixer	0.343 $\pm$ 0.361	0.399 $\pm$ 0.335	0.284 $\pm$ 0.266	0.441 $\pm$ 0.328	0.775 $\pm$ 0.138	0.842 $\pm$ 0.226	0.481 $\pm$ 0.564
	FRets	0.269 $\pm$ 0.026	0.408 $\pm$ 0.029	0.262 $\pm$ 0.022	0.490 $\pm$ 0.024	0.713 $\pm$ 0.045	0.915 $\pm$ 0.078	0.296 $\pm$ 0.046
	<i>flat-value persistence</i>	0.720 $\pm$ 0.098	0.712 $\pm$ 0.081	0.566 $\pm$ 0.097	0.713 $\pm$ 0.081	0.898 $\pm$ 0.046	0.713 $\pm$ 0.065	1.019 $\pm$ 0.051
per-window	SegRNN	0.537 $\pm$ 0.106	0.684 $\pm$ 0.089	0.535 $\pm$ 0.105	0.720 $\pm$ 0.071	0.881 $\pm$ 0.028	0.993 $\pm$ 0.006	0.541 $\pm$ 0.108
	xPatch	0.545 $\pm$ 0.092	0.685 $\pm$ 0.078	0.537 $\pm$ 0.093	0.717 $\pm$ 0.065	0.856 $\pm$ 0.042	0.970 $\pm$ 0.020	0.562 $\pm$ 0.090
	iTransformer	0.506 $\pm$ 0.122	0.653 $\pm$ 0.106	0.502 $\pm$ 0.120	0.695 $\pm$ 0.084	0.856 $\pm$ 0.046	0.987 $\pm$ 0.010	0.513 $\pm$ 0.125
	PatchTST	0.534 $\pm$ 0.106	0.668 $\pm$ 0.092	0.519 $\pm$ 0.103	0.698 $\pm$ 0.076	0.838 $\pm$ 0.051	0.941 $\pm$ 0.018	0.568 $\pm$ 0.107
	TiDE	0.591 $\pm$ 0.068	0.700 $\pm$ 0.080	0.556 $\pm$ 0.096	0.717 $\pm$ 0.084	0.854 $\pm$ 0.046	0.892 $\pm$ 0.126	0.671 $\pm$ 0.093
	RLinear	0.592 $\pm$ 0.069	0.700 $\pm$ 0.080	0.556 $\pm$ 0.096	0.716 $\pm$ 0.083	0.853 $\pm$ 0.046	0.888 $\pm$ 0.124	0.676 $\pm$ 0.093
	PatchMixer	0.624 $\pm$ 0.083	0.706 $\pm$ 0.105	0.565 $\pm$ 0.122	0.718 $\pm$ 0.109	0.862 $\pm$ 0.047	0.850 $\pm$ 0.192	0.766 $\pm$ 0.226
	DLinear	0.630 $\pm$ 0.096	0.697 $\pm$ 0.087	0.554 $\pm$ 0.101	0.703 $\pm$ 0.086	0.854 $\pm$ 0.053	0.805 $\pm$ 0.100	0.795 $\pm$ 0.111
	TSMixer	0.374 $\pm$ 0.281	0.477 $\pm$ 0.337	0.353 $\pm$ 0.257	0.519 $\pm$ 0.328	0.809 $\pm$ 0.039	0.926 $\pm$ 0.108	0.424 $\pm$ 0.342
	FRets	0.431 $\pm$ 0.048	0.579 $\pm$ 0.046	0.421 $\pm$ 0.050	0.627 $\pm$ 0.043	0.793 $\pm$ 0.038	0.942 $\pm$ 0.047	0.459 $\pm$ 0.047
	<i>flat-value persistence</i>	0.558 $\pm$ 0.079	0.704 $\pm$ 0.064	0.558 $\pm$ 0.079	0.737 $\pm$ 0.052	0.893 $\pm$ 0.027	0.998 $\pm$ 0.001	0.560 $\pm$ 0.078
	<i>occurrence-persistence</i>	0.633 $\pm$ 0.078	0.628 $\pm$ 0.074	0.480 $\pm$ 0.082	0.628 $\pm$ 0.074	0.836 $\pm$ 0.048	0.642 $\pm$ 0.075	1.016 $\pm$ 0.043
per-day	SegRNN	0.558 $\pm$ 0.097	0.701 $\pm$ 0.078	0.555 $\pm$ 0.091	0.734 $\pm$ 0.061	0.900	0.992 $\pm$ 0.021	0.564 $\pm$ 0.109
	xPatch	0.558 $\pm$ 0.087	0.698 $\pm$ 0.071	0.551 $\pm$ 0.087	0.728 $\pm$ 0.061	0.849 $\pm$ 0.107	0.976 $\pm$ 0.044	0.572 $\pm$ 0.088
	iTransformer	0.530 $\pm$ 0.123	0.678 $\pm$ 0.107	0.530 $\pm$ 0.123	0.717 $\pm$ 0.085		1.000 $\pm$ 0.000	0.530 $\pm$ 0.123
	PatchTST	0.555 $\pm$ 0.107	0.685 $\pm$ 0.091	0.538 $\pm$ 0.107	0.712 $\pm$ 0.080	0.838 $\pm$ 0.057	0.940 $\pm$ 0.060	0.593 $\pm$ 0.109
	TiDE	0.610 $\pm$ 0.075	0.708 $\pm$ 0.101	0.566 $\pm$ 0.117	0.720 $\pm$ 0.107	0.848 $\pm$ 0.068	0.871 $\pm$ 0.157	0.711 $\pm$ 0.073
	RLinear	0.610 $\pm$ 0.085	0.708 $\pm$ 0.108	0.568 $\pm$ 0.126	0.720 $\pm$ 0.114	0.848 $\pm$ 0.075	0.870 $\pm$ 0.158	0.712 $\pm$ 0.070
	PatchMixer	0.626 $\pm$ 0.074	0.702 $\pm$ 0.114	0.562 $\pm$ 0.128	0.712 $\pm$ 0.120	0.854 $\pm$ 0.064	0.836 $\pm$ 0.211	0.786 $\pm$ 0.224
	DLinear	0.631 $\pm$ 0.117	0.689 $\pm$ 0.105	0.546 $\pm$ 0.119	0.694 $\pm$ 0.104	0.851 $\pm$ 0.067	0.782 $\pm$ 0.109	0.820 $\pm$ 0.118
	TSMixer	0.364 $\pm$ 0.298	0.467 $\pm$ 0.352	0.347 $\pm$ 0.282	0.629 $\pm$ 0.137	0.810 $\pm$ 0.111	0.922 $\pm$ 0.133	0.404 $\pm$ 0.342
	FRets	0.444 $\pm$ 0.067	0.590 $\pm$ 0.076	0.433 $\pm$ 0.074	0.633 $\pm$ 0.072	0.778 $\pm$ 0.061	0.932 $\pm$ 0.067	0.477 $\pm$ 0.042
	<i>flat-value persistence</i>	0.562 $\pm$ 0.060	0.706 $\pm$ 0.046	0.559 $\pm$ 0.057	0.737 $\pm$ 0.036	0.879	0.992 $\pm$ 0.023	0.567 $\pm$ 0.069
	<i>occurrence-persistence</i>	0.624 $\pm$ 0.108	0.619 $\pm$ 0.100	0.472 $\pm$ 0.105	0.619 $\pm$ 0.100	0.829 $\pm$ 0.069	0.634 $\pm$ 0.096	1.013 $\pm$ 0.060

Table S15 Verification panel — Proton SPE (24 h). Event skill at a 1-day historical horizon and a 24 h forecast horizon, on the univariate track binarized at the proton ≥ 10 pfu solar-proton-event threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.026 $\pm$ 0.024	0.049 $\pm$ 0.041	0.025 $\pm$ 0.023	0.117 $\pm$ 0.045	0.410 $\pm$ 0.037	0.615 $\pm$ 0.112	0.047 $\pm$ 0.054
	xPatch	0.046 $\pm$ 0.079	0.071 $\pm$ 0.109	0.039 $\pm$ 0.063	0.118 $\pm$ 0.094	0.407 $\pm$ 0.100	0.523 $\pm$ 0.201	0.113 $\pm$ 0.212
	iTransformer	0.053 $\pm$ 0.078	0.084 $\pm$ 0.113	0.046 $\pm$ 0.065	0.119 $\pm$ 0.117	0.385 $\pm$ 0.152	0.371 $\pm$ 0.098	0.135 $\pm$ 0.198
	PatchTST	0.053 $\pm$ 0.086	0.080 $\pm$ 0.118	0.045 $\pm$ 0.069	0.108 $\pm$ 0.120	0.366 $\pm$ 0.165	0.339 $\pm$ 0.069	0.150 $\pm$ 0.230
	TiDE	0.061 $\pm$ 0.082	0.095 $\pm$ 0.112	0.053 $\pm$ 0.065	0.147 $\pm$ 0.090	0.442 $\pm$ 0.095	0.519 $\pm$ 0.226	0.149 $\pm$ 0.214
	RLinear	0.059 $\pm$ 0.081	0.092 $\pm$ 0.112	0.051 $\pm$ 0.065	0.143 $\pm$ 0.091	0.438 $\pm$ 0.097	0.527 $\pm$ 0.253	0.146 $\pm$ 0.212
	PatchMixer	0.050 $\pm$ 0.080	0.079 $\pm$ 0.112	0.044 $\pm$ 0.065	0.121 $\pm$ 0.107	0.398 $\pm$ 0.124	0.430 $\pm$ 0.096	0.122 $\pm$ 0.201
	DLinear	0.055 $\pm$ 0.066	0.072 $\pm$ 0.074	0.040 $\pm$ 0.042	0.082 $\pm$ 0.068	0.330 $\pm$ 0.129	0.145 $\pm$ 0.057	0.352 $\pm$ 0.358
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.059 $\pm$ 0.120	0.072 $\pm$ 0.131	0.041 $\pm$ 0.077	0.080 $\pm$ 0.132	0.314 $\pm$ 0.312	0.131 $\pm$ 0.160	0.238 $\pm$ 0.437
	<i>flat-value persistence</i>	0.113 $\pm$ 0.069	0.114 $\pm$ 0.068	0.065 $\pm$ 0.040	0.114 $\pm$ 0.068	0.398 $\pm$ 0.109	0.123 $\pm$ 0.068	0.970 $\pm$ 0.083
per-window	SegRNN	0.035 $\pm$ 0.017	0.056 $\pm$ 0.026	0.035 $\pm$ 0.017	0.165 $\pm$ 0.042	0.469 $\pm$ 0.035	0.984 $\pm$ 0.016	0.035 $\pm$ 0.017
	xPatch	0.032 $\pm$ 0.024	0.051 $\pm$ 0.038	0.032 $\pm$ 0.025	0.151 $\pm$ 0.056	0.385 $\pm$ 0.084	0.940 $\pm$ 0.068	0.034 $\pm$ 0.026
	iTransformer	0.025 $\pm$ 0.016	0.040 $\pm$ 0.026	0.025 $\pm$ 0.016	0.138 $\pm$ 0.045	0.421 $\pm$ 0.089	0.973 $\pm$ 0.020	0.025 $\pm$ 0.016
	PatchTST	0.025 $\pm$ 0.020	0.041 $\pm$ 0.033	0.025 $\pm$ 0.020	0.132 $\pm$ 0.068	0.371 $\pm$ 0.125	0.930 $\pm$ 0.063	0.027 $\pm$ 0.021
	TiDE	0.050 $\pm$ 0.025	0.080 $\pm$ 0.037	0.050 $\pm$ 0.025	0.198 $\pm$ 0.047	0.459 $\pm$ 0.042	0.970 $\pm$ 0.006	0.052 $\pm$ 0.025
	RLinear	0.044 $\pm$ 0.024	0.071 $\pm$ 0.036	0.044 $\pm$ 0.024	0.186 $\pm$ 0.048	0.469 $\pm$ 0.043	0.979 $\pm$ 0.011	0.046 $\pm$ 0.025
	PatchMixer	0.047 $\pm$ 0.032	0.075 $\pm$ 0.050	0.048 $\pm$ 0.032	0.187 $\pm$ 0.065	0.429 $\pm$ 0.073	0.949 $\pm$ 0.035	0.050 $\pm$ 0.035
	DLinear	0.080 $\pm$ 0.065	0.122 $\pm$ 0.092	0.081 $\pm$ 0.064	0.225 $\pm$ 0.091	0.397 $\pm$ 0.083	0.841 $\pm$ 0.053	0.098 $\pm$ 0.079
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.053 $\pm$ 0.108	0.078 $\pm$ 0.154	0.053 $\pm$ 0.108	0.130 $\pm$ 0.197	0.298 $\pm$ 0.276	0.563 $\pm$ 0.442	0.066 $\pm$ 0.131
	<i>flat-value persistence</i>	0.047 $\pm$ 0.016	0.074 $\pm$ 0.023	0.047 $\pm$ 0.016	0.191 $\pm$ 0.033	0.441 $\pm$ 0.042	0.959 $\pm$ 0.016	0.049 $\pm$ 0.016
	<i>occurrence-persistence</i>	0.500 $\pm$ 0.105	0.499 $\pm$ 0.103	0.414 $\pm$ 0.106	0.499 $\pm$ 0.103	0.683 $\pm$ 0.098	0.579 $\pm$ 0.101	1.008 $\pm$ 0.022
per-day	SegRNN	0.037 $\pm$ 0.036	0.060 $\pm$ 0.059	0.037 $\pm$ 0.036	0.165 $\pm$ 0.089		1.000 $\pm$ 0.000	0.037 $\pm$ 0.036
	xPatch	0.030 $\pm$ 0.022	0.047 $\pm$ 0.036	0.030 $\pm$ 0.022	0.138 $\pm$ 0.066	0.296 $\pm$ 0.119	0.876 $\pm$ 0.170	0.034 $\pm$ 0.024
	iTransformer	0.032 $\pm$ 0.028	0.051 $\pm$ 0.046	0.032 $\pm$ 0.028	0.149 $\pm$ 0.074	0.364	0.971 $\pm$ 0.079	0.033 $\pm$ 0.030
	PatchTST	0.020 $\pm$ 0.024	0.033 $\pm$ 0.040	0.021 $\pm$ 0.024	0.131 $\pm$ 0.095	0.144	0.875 $\pm$ 0.347	0.022 $\pm$ 0.023
	TiDE	0.054 $\pm$ 0.047	0.086 $\pm$ 0.074	0.054 $\pm$ 0.047	0.203 $\pm$ 0.092		1.000 $\pm$ 0.000	0.054 $\pm$ 0.047
	RLinear	0.044 $\pm$ 0.042	0.070 $\pm$ 0.066	0.044 $\pm$ 0.042	0.180 $\pm$ 0.097		1.000 $\pm$ 0.000	0.044 $\pm$ 0.042
	PatchMixer	0.057 $\pm$ 0.056	0.090 $\pm$ 0.087	0.057 $\pm$ 0.056	0.203 $\pm$ 0.108	0.282	0.967 $\pm$ 0.093	0.058 $\pm$ 0.055
	DLinear	0.089 $\pm$ 0.083	0.135 $\pm$ 0.122	0.089 $\pm$ 0.083	0.239 $\pm$ 0.127	0.429 $\pm$ 0.171	0.879 $\pm$ 0.114	0.103 $\pm$ 0.097
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FReTS	0.050 $\pm$ 0.114	0.072 $\pm$ 0.162	0.050 $\pm$ 0.114	0.187 $\pm$ 0.286	0.321 $\pm$ 0.312	0.670 $\pm$ 0.276	0.065 $\pm$ 0.139
	<i>flat-value persistence</i>	0.051 $\pm$ 0.051	0.080 $\pm$ 0.079	0.051 $\pm$ 0.051	0.192 $\pm$ 0.098	0.329	0.975 $\pm$ 0.069	0.052 $\pm$ 0.050
	<i>occurrence-persistence</i>	0.505 $\pm$ 0.090	0.502 $\pm$ 0.087	0.417 $\pm$ 0.096	0.502 $\pm$ 0.087	0.688 $\pm$ 0.080	0.581 $\pm$ 0.088	1.012 $\pm$ 0.024

Table S16 Verification panel — XRS M-class (24 h). Event skill at a 1-day historical horizon and a 24 h forecast horizon, on the univariate track binarized at the M-class ($\geq 10^{-5}$ W m $^{-2}$) threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

Gran.	Model	TSS	HSS	CSI	MCC	SEDI	precision	FB
per-point	SegRNN	0.002 $\pm$ 0.002	0.005 $\pm$ 0.003	0.002 $\pm$ 0.002	0.044 $\pm$ 0.018	0.457 $\pm$ 0.043	0.859 $\pm$ 0.164	0.003 $\pm$ 0.002
	xPatch	0.003 $\pm$ 0.004	0.005 $\pm$ 0.007	0.003 $\pm$ 0.004	0.035 $\pm$ 0.036	0.379 $\pm$ 0.132	0.427 $\pm$ 0.488	0.006 $\pm$ 0.008
	iTransformer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.007 $\pm$ 0.008	0.294 $\pm$ 0.086	0.607 $\pm$ 0.297	0.000 $\pm$ 0.000
	PatchTST	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	TiDE	0.005 $\pm$ 0.001	0.009 $\pm$ 0.003	0.005 $\pm$ 0.001	0.061 $\pm$ 0.011	0.477 $\pm$ 0.022	0.860 $\pm$ 0.069	0.005 $\pm$ 0.002
	RLinear	0.003 $\pm$ 0.001	0.005 $\pm$ 0.002	0.003 $\pm$ 0.001	0.048 $\pm$ 0.014	0.468 $\pm$ 0.071	0.967 $\pm$ 0.070	0.003 $\pm$ 0.001
	PatchMixer	0.002 $\pm$ 0.003	0.003 $\pm$ 0.005	0.002 $\pm$ 0.003	0.026 $\pm$ 0.036	0.378 $\pm$ 0.206	0.535 $\pm$ 0.605	0.013 $\pm$ 0.019
	DLinear	0.004 $\pm$ 0.003	0.008 $\pm$ 0.004	0.004 $\pm$ 0.002	0.026 $\pm$ 0.014	0.367 $\pm$ 0.054	0.248 $\pm$ 0.324	0.054 $\pm$ 0.105
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.002 $\pm$ 0.005	0.002 $\pm$ 0.006	0.001 $\pm$ 0.003	0.005 $\pm$ 0.014	0.316	0.006 $\pm$ 0.017	0.146 $\pm$ 0.403
	<i>flat-value persistence</i>	0.017 $\pm$ 0.006	0.017 $\pm$ 0.007	0.009 $\pm$ 0.004	0.017 $\pm$ 0.007	0.326 $\pm$ 0.029	0.018 $\pm$ 0.007	0.986 $\pm$ 0.205
per-window	SegRNN	0.006 $\pm$ 0.005	0.011 $\pm$ 0.008	0.006 $\pm$ 0.005	0.069 $\pm$ 0.028	0.386 $\pm$ 0.092	0.936 $\pm$ 0.097	0.006 $\pm$ 0.005
	xPatch	0.008 $\pm$ 0.010	0.015 $\pm$ 0.017	0.008 $\pm$ 0.010	0.066 $\pm$ 0.056	0.295 $\pm$ 0.153	0.518 $\pm$ 0.489	0.016 $\pm$ 0.021
	iTransformer	0.000 $\pm$ 0.001	0.000 $\pm$ 0.001	0.000 $\pm$ 0.001	0.019 $\pm$ 0.026	0.192	0.750 $\pm$ 0.694	0.000 $\pm$ 0.001
	PatchTST	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	TiDE	0.012 $\pm$ 0.005	0.024 $\pm$ 0.008	0.012 $\pm$ 0.005	0.105 $\pm$ 0.023	0.426 $\pm$ 0.059	0.909 $\pm$ 0.078	0.014 $\pm$ 0.004
	RLinear	0.007 $\pm$ 0.004	0.014 $\pm$ 0.008	0.007 $\pm$ 0.004	0.082 $\pm$ 0.023	0.411	0.992 $\pm$ 0.023	0.007 $\pm$ 0.004
	PatchMixer	0.007 $\pm$ 0.011	0.014 $\pm$ 0.021	0.007 $\pm$ 0.011	0.058 $\pm$ 0.072	0.371 $\pm$ 0.169	0.628 $\pm$ 0.548	0.011 $\pm$ 0.011
	DLinear	0.013 $\pm$ 0.008	0.025 $\pm$ 0.016	0.013 $\pm$ 0.008	0.097 $\pm$ 0.032	0.371 $\pm$ 0.067	0.759 $\pm$ 0.097	0.017 $\pm$ 0.011
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.006 $\pm$ 0.018	0.012 $\pm$ 0.032	0.006 $\pm$ 0.017	0.049 $\pm$ 0.139	0.360	0.156 $\pm$ 0.433	0.021 $\pm$ 0.059
	<i>flat-value persistence</i>	0.016 $\pm$ 0.006	0.030 $\pm$ 0.012	0.016 $\pm$ 0.006	0.113 $\pm$ 0.025	0.407 $\pm$ 0.034	0.846 $\pm$ 0.040	0.018 $\pm$ 0.007
	<i>occurrence-persistence</i>	0.224 $\pm$ 0.086	0.233 $\pm$ 0.100	0.143 $\pm$ 0.059	0.233 $\pm$ 0.100	0.511 $\pm$ 0.152	0.259 $\pm$ 0.108	0.960 $\pm$ 0.177
per-day	SegRNN	0.032 $\pm$ 0.038	0.060 $\pm$ 0.070	0.032 $\pm$ 0.038	0.229 $\pm$ 0.038		1.000 $\pm$ 0.000	0.032 $\pm$ 0.038
	xPatch	0.009 $\pm$ 0.025	0.017 $\pm$ 0.047	0.009 $\pm$ 0.025	0.210		1.000	0.009 $\pm$ 0.025
	iTransformer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	PatchTST	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	TiDE	0.032 $\pm$ 0.038	0.060 $\pm$ 0.070	0.032 $\pm$ 0.038	0.229 $\pm$ 0.038		1.000 $\pm$ 0.000	0.032 $\pm$ 0.038
	RLinear	0.013 $\pm$ 0.037	0.025 $\pm$ 0.068	0.013 $\pm$ 0.037	0.256		1.000	0.013 $\pm$ 0.037
	PatchMixer	0.013 $\pm$ 0.037	0.025 $\pm$ 0.068	0.013 $\pm$ 0.037	0.256		1.000	0.013 $\pm$ 0.037
	DLinear	0.022 $\pm$ 0.039	0.042 $\pm$ 0.073	0.022 $\pm$ 0.039	0.233 $\pm$ 0.064		1.000 $\pm$ 0.000	0.022 $\pm$ 0.039
	TSMixer	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000				0.000 $\pm$ 0.000
	FRets	0.000 $\pm$ 0.001	0.000 $\pm$ 0.001	0.000 $\pm$ 0.000	-0.003		0.000	0.025 $\pm$ 0.069
	<i>flat-value persistence</i>	0.032 $\pm$ 0.038	0.060 $\pm$ 0.070	0.032 $\pm$ 0.038	0.229 $\pm$ 0.038		1.000 $\pm$ 0.000	0.032 $\pm$ 0.038
	<i>occurrence-persistence</i>	0.224 $\pm$ 0.070	0.237 $\pm$ 0.085	0.145 $\pm$ 0.051	0.238 $\pm$ 0.086	0.517 $\pm$ 0.127	0.269 $\pm$ 0.097	0.909 $\pm$ 0.140

Table S17 Verification panel — XRS X-class (24 h). Event skill at a 1-day historical horizon and a 24 h forecast horizon, on the univariate track binarized at the X-class ($\geq 10^{-4}$ W m $^{-2}$) threshold, by granularity (per-point / per-window / per-day), reported as 5-fold mean $\pm$ 95% CI in the compact form $m_{\pm c}$. Undefined metrics are left blank; the conditions are given in the appendix text above.

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