A moisture-weighted typical-month selection for environmental exposure screening: design and evaluation of CEY20 at 14 locations

Wadim Okley[1] · ORCID 0009-0000-2257-9728

[1] Independent researcher

Correspondence: wadim.okley@getclimetry.com

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Abstract

Typical-year datasets condense multi-year hourly records into one year for engineering calculations. Established methods were designed for energy and solar applications. Moisture and thermal exposure screening needs a typical year that preserves humid-hour statistics. This study presents CEY20, a typical-month selection on the global 0.25° ERA5-Land land grid for 2006–2025. For each point and calendar month it selects the source year whose ten monthly temperature and humidity features are closest to their 20-year means, with 71 % of the weight on moisture features. The released version smooths month interfaces with a 6-hour excess-step ramp.

Target checks were specified before target outcomes at 14 locations from tropical to subarctic climates. Hourly diagnostics were defined subsequently, before their computation. The released version was evaluated under a later amendment with unchanged definitions, paired with the unsmoothed construction. Results for the released version:

- **Joint distribution.** The composite year has a smaller distance to the pooled 20-year joint temperature–humidity distribution than every individual source year at 9 of 14 locations.
- **Spells and applications.** Of 196 humid-spell and drying-gap statistics, 195 fall within the actual-year range, as do 194 of 196 screening outputs; both exceptions are closer to the pooled climate than every actual year.
- **Strict tolerances.** It meets ±5 % on annual exposure hours in 33 of 42 checks, ±0.5 °C on monthly mean temperature in 109 of 168 checks and ±2 percentage points on monthly mean humidity in 153 of 168 checks. Median deviations are 0.31 °C and 0.61 percentage points.
- **Month interfaces.** Under the primary reference, boundary steps above the 99th percentile of natural hourly changes fall from 68 to 0 of 150 cross-year boundaries for temperature. The largest change within the 12-hour smoothing window still exceeds it at 14 of 150.
- **Where deviations arise.** Deviations beyond tolerance concentrate at arid and cold continental locations.
- **Comparison with Finkelstein–Schafer selections.** On the same data, all unsmoothed, CEY20 meets more annual exposure and monthly humidity checks. A temperature-oriented variant meets more monthly temperature checks.

- **California.** At California weather stations, the departure of the selected year from its own source climatology is smaller than the source–station discrepancy at 37–39 of 40 stations.

Relative to the unsmoothed construction, the annual tolerance counts are unchanged, one monthly temperature check enters tolerance and one humidity check leaves it. Results describe in-sample agreement for the tested points and quantities from one reanalysis at 0.25°. Screening is the intended application, and application-specific suitability remains to be evaluated.

1. Introduction

Typical years and their design aims

Typical-year datasets assemble one representative year from a multi-year hourly record, usually by choosing each calendar month from one source year. The established procedures were designed for energy and solar applications:

- The Sandia method family and its NREL successors TMY2 and TMY3 rank candidate months by a weighted Finkelstein–Schafer (FS) statistic of daily indices that include solar radiation. Secondary ranking and persistence screening follow (Finkelstein and Schafer, 1971; Wilcox and Marion, 2008).
- ISO 15927-4 specifies an FS-based reference year for heating and cooling energy (ISO 15927-4:2005).
- Reanalysis-based typical years such as PVGIS-TMY extend the approach to global grids. They are validated mainly through degree days and building energy simulations (Huld et al., 2018).

Moisture exposure has different priorities

Durability, corrosion and condensation screening depend on three things:

- the duration of high relative humidity;
- near-saturation hours;
- the coupling of temperature and humidity.

Moisture reference years exist, but they usually target critical rather than typical conditions (Cornick et al., 2003; Kalamees and Vinha, 2004). A typical year optimised for energy statistics need not preserve humid-hour counts.

Contributions

CEY20 ("Climetry Environmental Year", 2006–2025) addresses this gap. It is a typical-month selection for moisture and thermal exposure screening on a global 0.25° land grid from ERA5-Land (Muñoz-Sabater et al., 2021). It weights humidity features explicitly, covers every land point, and in its released version smooths month interfaces. This paper makes three contributions:

1. **The method, exactly as implemented.** Section 2 states the selection rule and the interface smoothing with their parameters and their status.
2. **An evaluation at 14 locations.** Pre-specified target checks assess annual exposure hours and monthly means. Subsequent hourly diagnostics assess distribution, sequence properties and month-interface continuity. Stability analyses and illustrative screening applications are also reported.

3. **Comparisons.** CEY20 is compared with Finkelstein–Schafer selections on the same data. The paper also summarises a station comparison with two published typical years in California. The full comparison is reported in a companion data descriptor (Okley, 2026a).

2. Method

2.1 Source data

The source is ERA5-Land hourly data (Muñoz-Sabater, 2019; Muñoz-Sabater et al., 2021) for the 20 candidate years 2006–2025, sampled at the land points of a 0.25° product grid.

- **Grid.** Each 0.25° node takes the values of one point of the 0.1° ERA5-Land grid by nearest-index selection, without interpolation or averaging.
- **Variables.** 2 m air temperature T, 2 m dew-point temperature Td and surface pressure p.
- **Time.** Times are UTC. The year has 365 days: 29 February of leap years is removed, so every year has 8760 hours.

2.2 Derived humidity

Relative humidity follows from T and Td with the Magnus form and the coefficients of Bolton (1980), over liquid water at all temperatures:

$$e_s(T) = 6.112\,\exp\!\left(\frac{17.67\,T}{T+243.5}\right)\ \text{hPa}, \qquad \mathrm{RH} = 100\,\frac{e_s(T_d)}{e_s(T)},$$

clipped to 0–100 %. Further quantities:

- **Absolute humidity**, used only in the selection: $\mathrm{AH} = 216.7\,e_s(T_d)/(T+273.15)$ g m^{-3}, with T and Td in °C.
- **Dew-point depression:** D = T − Td.

2.3 Monthly features and selection

For each point, calendar month and candidate year y, ten features $f_k(y)$ are computed from that month's hours (Table 1). Percentiles use linear interpolation; the daily temperature range uses UTC days. The score of a candidate is

$$S(y) = \sum_{k=1}^{10} w_k\,\frac{|f_k(y) - c_k|}{s_k},$$

where c_k is the mean of feature k over all 20 candidate years. The year with the smallest score is selected; ties go to the earliest year. The scales s_k are fixed constants, identical for all points and months.

Table 1. Selection features, weights and scales (pp = percentage points).

k	Feature	Weight w_k	Scale s_k
1	Mean T	1.5	8 °C
2	95th percentile T	0.8	10 °C
3	Mean RH	1.5	20 pp

k	Feature	Weight w_k	Scale s_k
4	90th percentile RH	1.0	20 pp
5	Mean AH	1.0	8 g m^{-3}
6	10th percentile D	0.8	8 °C
7	Hours RH ≥ 80 %	1.2	180 h
8	Hours RH ≥ 90 %	1.0	120 h
9	Hours D ≤ 2 °C	1.0	120 h
10	Mean daily T range	0.7	8 °C

2.4 Design of the weighting

How the weight is distributed. The weighting puts moisture first:

- moisture-related features (k = 3–9): 7.5 of the nominal weight of 10.5 (71.4 %);
- thermal level and variability (k = 1, 2, 10): 3.0 (28.6 %);
- the three exceedance-hour counts (k = 7–9), which directly target humid and near-saturated hours: 3.2 (30.5 %).

Only the ratios w_k/s_k affect the ranking.

Status of the parameters. The weights and scales are expert-set engineering parameters. They are not calibrated coefficients; their documented rationale is retrospective, and no formal elicitation took place. Section 4.3 tests how sensitive the results are to them.

Limits of the features.

- The features overlap: the counts are nested and correlated, and AH depends on T and Td.
- RH ≥ 80 % hours are not the standardised time of wetness of ISO 9223, which adds a temperature condition.
- A 2 °C dew-point depression is not a universal condensation threshold.

2.5 Month-interface smoothing (released version 2)

The selected months are copied unchanged and concatenated. Where adjacent months come from different source years, the interface can show an abrupt step between source hours that were not consecutive. Version 2 therefore applies an excess-step linear ramp, inspired by the 6-hour junction smoothing of TMY3 (Wilcox and Marion, 2008, section 2.6).

Excess step. Let b be the first hour of a month. The excess step is

$$E = (x_b - x_{b-1}) - \tfrac{1}{2}\left[(x_{b-1} - x_{b-2}) + (x_{b+1} - x_b)\right],$$

that is, the step at the join minus the mean of the two adjacent within-month steps.

Ramp. With $w_k = (7 - k)/6$ for k = 1, …, 6, the values x_{b-k} are raised by $\tfrac{1}{2}Ew_k$ and the values x_{b-1+k} are lowered by $\tfrac{1}{2}Ew_k$. All corrections are computed from the unmodified values.

Where it applies.

- The ramp applies to T, Td and p at all 12 interfaces, including December–January. It modifies at most 144 of 8760 hours per point.
- Interfaces between consecutive source hours (same year) are left unchanged. A February–March interface in a leap year is not consecutive, because 29 February is removed.
- T and Td are smoothed together where all window values are finite. Pressure is smoothed separately, unless the result would be non-finite or non-positive.

Humidity constraint. In modified hours, Td is limited to T. RH is not stored in the product; it is derived from the stored, smoothed T and Td with the formula of Section 2.2.

Adjusted hours are synthetic. The recorded source year documents provenance, not exact hourly values.

2.6 Relation to established methods

Table 2. CEY20 compared with ISO 15927-4 and the TMY3 procedure (verified statements only).

Aspect	ISO 15927-4:2005	TMY3 (Wilcox and Marion, 2008)	CEY20
Purpose	heating and cooling energy	solar and building energy	moisture and thermal exposure screening
Similarity measure	FS statistic of daily values	weighted FS statistic of daily indices	weighted, scaled L1 distance of 10 monthly features
Secondary criteria	wind as secondary parameter	closeness of monthly mean/median, persistence	none
Month junctions	not verified	6 h smoothing on both sides	6 h excess-step ramp (version 2)
Variables	include radiation and wind	include solar radiation and wind	temperature and humidity only

CEY20 is a methodological adaptation for exposure screening. No conformity with ISO 15927-4 or equivalence with TMY3 is claimed.

3. Evaluation design

3.1 Pre-specification and chronology

The original target protocol, locations, tolerances, sensitivity analyses and reporting rules were fixed and hashed before the target outcomes were computed. Hourly diagnostic definitions were fixed after the S3 selection run and before diagnostic computation, without predefined diagnostic pass/fail limits. Later changes were recorded as amendments. The chronology:

Date	Step
31 Oct 2026	Target run of the unsmoothed construction (version 1)
after the target run	Hourly diagnostics defined before computation, without pass/fail limits
1 Nov 2026	Development evaluation of the interface smoothing
9 Nov 2026	Amendment V2 (pre-specified, frozen r3) re-evaluates the released version 2

Amendment V2. It was declared after the version-1 results were known, and the version-1 boundary findings motivated the smoothing. It is therefore outcome-informed. Before it was fixed, the following evidence on version 2 existed:

- the global development evaluation of the smoothing over all land points;
- stored annual exposure-hour changes, boundary steps and window transitions at the study points, including reported ramp-correction magnitudes there;
- the California station comparison and the data descriptor, both based on version 2.

The version-2 Target-1 and D4 values therefore recompute previously stored quantities under the frozen definitions; they are not new outcomes.

Not fully blind. Eight of the 14 locations had been inspected while the weight rationale was drafted.

3.2 Locations and conventions

Locations. Fourteen locations cover humid tropical, monsoon, hot arid, humid subtropical, maritime, continental, subarctic and high-elevation equatorial climates: Singapore, Mumbai, Dubai, Houston, Frankfurt, London, Seattle, San Francisco, Helsinki, Fairbanks, Chicago, Phoenix, Denver and Quito.

Cell assignment. Each location uses the nearest 0.25° land point, resolved once and never substituted.

Common conventions. Both sides of every comparison use the same cell, UTC hours and days, water-relative RH, the thresholds RH ≥ 80 %, RH ≥ 90 % and D ≤ 2 °C, and the 365-day calendar.

Requested coordinates, grid cells and distances are listed in Appendix B.

3.3 Reference and tolerances

The reference for each quantity is the mean over the 20 actual years. The tolerances are deliberately strict engineering targets, not standardised requirements or confidence intervals.

1. **Annual exposure hours** per location and metric (RH ≥ 80 %, RH ≥ 90 %, D ≤ 2 °C): within ±5 % of the reference (42 checks). There is no absolute-hour floor, so rare events at dry locations are held to the same relative tolerance.
2. **Monthly means** per location and month: $|\Delta T| \leq 0.5$ °C and $|\Delta RH| \leq 2$ percentage points (168 checks each).

The selection uses the same archive and overlapping features. Agreement therefore describes in-sample agreement with the selected reference quantities.

3.4 Distribution and sequence diagnostics

Five diagnostics describe hourly properties that the selection does not use directly:

- **D1:** the joint T/RH distribution, ranked against each actual year;
- **D2:** humid-spell lengths and drying gaps;
- **D3:** temperature during humid hours;
- **D4:** hour-to-hour changes at month boundaries against the 99th percentile of natural hourly changes. For the smoothed version, D4 also records the largest change anywhere within the smoothing window, and pressure is included (added 9 Nov 2026);
- **D5:** sensitivity to local-solar days and to saturation over ice. For version 2, both variant selections are smoothed with the same pinned function before evaluation (implementation clarification V2.1, approved before any version-2 outcome).

3.5 Stability and sensitivity

Sensitivity. The selection was repeated with:

- equal weights;
- each weight changed by ±25 %, one at a time and in joint moisture/thermal combinations;
- local interannual standard deviations as scales;
- the count block halved or removed;
- threshold brackets RH 78/82 %, 88/92 % and D 1/3 °C.

Leave-one-year-out (LOYO). Each year was removed in turn from the pool and the climatology.

These analyses concern the selection. They were run on the unsmoothed construction.

3.6 Comparison with Finkelstein–Schafer selections

Two FS-based variants were specified before computation and run on the same data:

- **FS-A** uses the six daily temperature and dew-point indices of TMY3, with their relative TMY3 weights.
- **FS-B** gives FS-A half of the weight and adds three daily exposure counts at 1/6 each.

Neither variant includes secondary ranking or persistence screening. All three constructions are compared unsmoothed.

3.7 Screening applications

Four applications were specified before computation:

- **A1:** temperature duration curves;
- **A2:** heat-pump screening with degree hours (heating base 15 °C, cooling base 24 °C) and cold-hour counts at the part-load class temperatures of EN 14825:2022;
- **A3:** calculated time of wetness with the levels of ISO 9223:2012, Annex B;
- **A4:** near-saturation hours and zero-crossing days.

Each value is placed within the 20 actual-year values. Regional envelopes in 2° × 2° boxes around seven centres describe spatial variation; Köppen classes are taken from Beck et al. (2023).

3.8 Provenance

Pins and gates. The pinned runners require abort-on-mismatch checks of code and inputs before any outcome is computed. Explicit gate records and execution evidence vary by run; the qualifications for the FS comparison and the screening applications are retained in the study package.

Released version 2. The product records its generating commit. Before any version-2 outcome, the evaluation checked three properties of the released files against the study selections, at the 14 locations and one region centre:

- that the selection is identical;
- that every hour outside the smoothing window equals the selected source year exactly;
- that every hour inside it equals the pinned smoothing implementation exactly.

All three held, with no mismatch (Section 4.4).

Original v1 product. The generating commit of the original unsmoothed product files is not recorded.

4. Results

4.1 Distribution and sequence properties

Joint distribution (D1). The binned joint T/RH distribution of the composite year is closer to the pooled 2006–2025 distribution than that of every single actual year at 9 of 14 locations in both versions (Hellinger distance). At the others it ranks 2nd (Singapore, Denver), 3rd (San Francisco), 5th (Phoenix; 4th in version 1) or 7th (Frankfurt) of 21. This compares binned distributions; it is not a formal adequacy test.

Spells and drying gaps (D2). 195 of 196 statistics of humid-spell length and drying-gap length lie within the range of the 20 actual years in both versions. The exception is one 10th-percentile drying gap at San Francisco: 3.0 h against 3.2 h. Smoothing changes 30 of 196 percentile positions, mostly through tied integer-hour values. Mean spell length tends to be shorter than the actual-year median (23 of 28 location–threshold combinations). Tied ranks limit interpretation of percentile positions. These within-range summaries do not establish preservation of temporal structure.

Temperature in humid hours (D3). The mean temperature during hours with RH ≥ 80 % is within 0.50 °C of the pooled reference at 11 of 14 locations in both versions. Chicago rounds to −0.50 °C in version 1 (−0.5002 °C) but lies just outside; it is −0.52 °C in version 2. Smoothing changes these differences by at most 0.033 °C. All 14 values lie within the actual-year range.

Convention sensitivity (D5). Using local-solar instead of UTC days changes the selection in 4 of 168 location-months and leaves the number of annual failures unchanged. The ice-saturation sensitivity gives eight versus nine Target-1 failures under different humidity conventions, in both versions. This comparison changes definitions as well as selections. The ice coefficients used (6.112 hPa, 22.46, 272.62 °C) are listed in the WMO CIMO Guide (2008) according to a secondary source; the primary citation has not been verified.

Table 3. Repeated distribution, sequence and convention diagnostics, released version 2 and unsmoothed version 1.

Diagnostic	Quantity	v2	v1
D1	Locations where the composite year is closer to the pooled distribution than every actual year	9 of 14	9 of 14
D2	Spell and gap statistics within the actual-year range	195 of 196	195 of 196
D2	Mean spell length below the actual-year median	23 of 28	23 of 28
D3	Locations with mean T in humid hours within 0.50 °C of the pooled reference	11 of 14	11 of 14
D3	Locations within the actual-year range	14 of 14	14 of 14
D5	Annual checks outside tolerance: baseline / local-solar days / ice saturation	9 / 9 / 8	9 / 9 / 8

Between versions, 30 of 196 D2 percentile positions change, the largest from the 70th to the 20th percentile (Mumbai median drying gap at RH ≥ 90 %, 13.0 → 12.5 h against an actual-year median of 13 h).

4.2 Agreement with the pre-specified tolerances

Table 4. Checks within the strict tolerances: released version 2 and unsmoothed version 1.

Quantity	Tolerance	Within, v2	Within, v1	Median abs. deviation, v2	Median abs. deviation, v1
Annual hours RH ≥ 80 %, RH ≥ 90 %, D ≤ 2 °C	±5 %	33 of 42	33 of 42	1.10 % (29.1 h)	0.98 % (31.7 h)
Monthly mean T	±0.5 °C	109 of 168	108 of 168	0.31 °C	0.31 °C
Monthly mean RH	±2 pp	153 of 168	154 of 168	0.61 pp	0.59 pp

Where the targets are met. Monthly humidity, the quantity most heavily weighted, is reproduced within tolerance in 91 % of location-months (version 1: 92 %), and monthly temperature in 65 % (64 %). Singapore and Quito meet every monthly temperature check, and ten of the 14 locations meet every annual exposure check, in both versions.

Where they are not. In version 2, checks outside tolerance comprise 9 of 42 annual exposure checks, 59 of 168 monthly temperature checks and 15 of 168 monthly humidity checks. All nine failed annual checks underestimate the reference and occur at Phoenix, Denver, Fairbanks and Chicago; they are the same nine checks as in version 1, with selected annual counts changed by at most 19 h. Across all 42 annual checks, 28 underestimate and 14 overestimate the reference. Two monthly results differ from version 1, both at Chicago: May temperature moves within tolerance (+0.55 → +0.49 °C) and March humidity outside it (+1.98 → +2.07 pp). The version-1 results are summarised in Section 4.8.

All checks outside tolerance are listed in Appendix A. The tolerances were not changed after the results were known.

4.3 Stability and sensitivity

Stability (LOYO). When one year is removed from both the candidate pool and reference, an average of 9.8 of 12 monthly selections remain unchanged. Annual exposure hours are within 5 % of the corresponding 19-year reference in 82 % of cases, with a median deviation of 1.1 %. These are selection-stability and 19-year-reference comparisons. They do not establish held-out hourly predictive performance or satisfaction of the failed full-reference targets.

Sensitivity. Annual checks outside tolerance remain under all tested sensitivity variants.

Change	Annual checks outside tolerance
Baseline	9
Single-weight ±25 %	7–9
Joint weight changes	7–8
Equal weights	7
Count block halved	9
Local scaling	10
Threshold brackets	7–8
Count block removed	14

None of the tested variants eliminates annual failures. Removing the count block increases the aggregate failure count from 9 to 14 in this run. These comparisons describe sensitivity to the tested specifications and do not establish a general causal benefit of the count block or robustness beyond those specifications.

4.4 Month interfaces and smoothing

Boundaries and reference. Of 154 inner boundaries, 150 join different source years; the other four join consecutive months of one source year and show no exceedance in either version. The unsmoothed boundary findings are summarised in Section 4.8. The reference comprises all hour-to-hour changes within ±72 h of the same boundary in the 20 actual years. Boundary hours are unmatched to reference hours, so these rates are descriptive and have no calibrated 1 % null interpretation. A supplementary reference restricted to 23→00 UTC changes gives higher rates.

Removing 29 February creates nonconsecutive source-hour transitions. In leap years the step from 28 February 23:00 to 1 March 00:00 is nonconsecutive and lies inside the February–March reference window; the reference is not adjusted for it. In version 2 such a February–March interface is smoothed even when both months come from the same leap year (Section 2.5). These observed jumps motivated the smoothing of version 2.

Released version 2. The released files reproduce the pinned smoothing exactly. Outside the smoothing window every value equals the selected source year; inside it every value equals the pinned implementation. At most 144 hours per location are modified (12 per boundary), and no hour inside the window has Td > T. Paired values use the unchanged references. Two quantities describe each boundary:

- J_b, the step at the boundary;
- M_b, the largest of the 13 hourly changes touching the 12-hour window.

Pressure is a diagnostic added by the amendment on 9 November 2026. Comparing a maximum over 13 changes with a single-change percentile is descriptive. These boundary steps had been computed during development (Section 3.1), so the version-2 values recompute them under the frozen definitions.

Table 5. Changes above the reference 99th percentile at the 150 cross-year inner boundaries, version 1 → version 2.

Variable	J_b	M_b
T	68 → 0	76 → 14
Td	85 → 0	95 → 26
RH	55 → 0	65 → 12
Surface pressure (added 9 Nov 2026)	125 → 0	126 → 39

- **December–January wrap (14 boundaries).** J_b exceeds at no boundary in version 2. M_b exceeds at 1, 1, 0 and 4 boundaries for T, Td, RH and pressure (version 1: 8, 12, 4 and 10).
- **Magnitudes.** At cross-year boundaries the median J_b falls from 2.60 to 0.43 °C (T) and from 2.81 to 0.22 °C (Td). The largest change within any window falls from 33.7 to 6.0 °C (T) and from 31.5 to 6.3 °C (Td).
- **Local increases.** The ramp spreads one step over 12 hours. Where a large natural change lies inside the window, the window maximum can rise: M_b is larger in version 2 at 31 of 150 cross-year boundaries for T.

- **Stricter reference.** Against the supplementary 23→00 UTC reference, M_b for T exceeds at 86 of 150 boundaries (version 1: 128), while J_b exceeds at 1.
- **Interpretation.** Under the primary reference, smoothing removes the exceedances of the single boundary step. It does not restore natural hourly variation within the window, and the window maxima still exceed the reference at some boundaries.

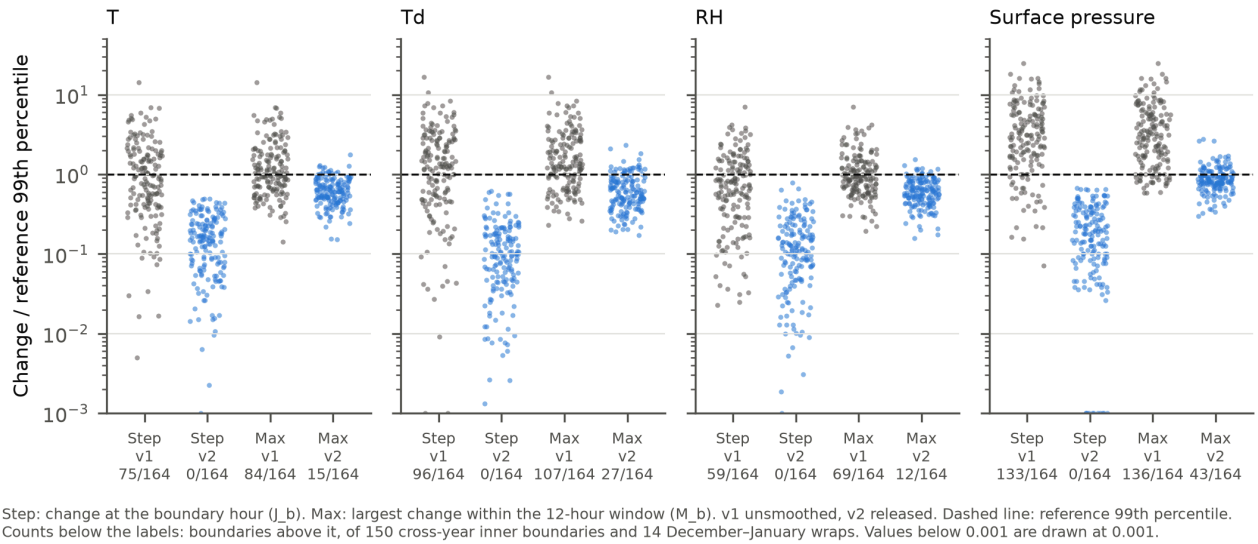


Figure 1. Hourly changes at month boundaries relative to the reference 99th percentile, unsmoothed version 1 (grey) and released version 2 (blue), at 150 cross-year inner boundaries and 14 December–January wraps of the 14 locations. Step: change at the boundary hour (J_b). Max: largest change within the 12-hour smoothing window (M_b). Each group combines the 150 inner and 14 wrap boundaries, so the counts below the labels (boundaries above the reference) use the denominator 164; Table 5 reports inner boundaries and the text reports wraps separately. Logarithmic scale; values below 0.001 are drawn at 0.001.

4.5 Comparison with Finkelstein–Schafer selections

Table 6. Checks within tolerance for CEY20 and two FS-based selections on the same data, all unsmoothed.

Method	Annual (of 42)	Monthly T (of 168)	Monthly RH (of 168)	Median abs. annual deviation	Median abs. ΔT (°C)	Median abs. ΔRH (pp)
CEY20	33	108	154	0.98 % (31.7 h)	0.31	0.59
FS-A	29	133	116	2.91 % (69.4 h)	0.20	1.14
FS-B	29	119	132	2.37 % (67.0 h)	0.28	0.87

What the comparison shows. In this unsmoothed, same-data comparison, CEY20's median absolute annual exposure-hour deviation is less than half that of either tested FS-based selection. CEY20 also meets the monthly humidity tolerance more often, while both FS-based selections meet the monthly temperature tolerance more often. This pattern is consistent with CEY20's emphasis on moisture-related features.

Caveat. The tolerances were set for CEY20, whose features overlap the target quantities, so the comparison favours CEY20 on those quantities by construction.

4.6 Comparison with stations and published typical years in California

The companion data descriptor (Okley, 2026a) of the released California dataset (Okley, 2026b) reports a pre-specified comparison at 40 California weather stations. It compares the released version 2 with PVGIS-TMY and NSRDB TMY against NOAA Integrated Surface Database climatologies.

- **Monthly checks.** CEY20 meets the monthly temperature tolerance in 125 and the humidity tolerance in 100 of 480 station-months. PVGIS-TMY meets them in 112 and 83, NSRDB TMY in 105 and 86.
- **Comparison of discrepancies.** The departure of CEY20 from its own 20-year ERA5-Land climatology is smaller than the discrepancy between that climatology and the station reference at 37–39 of 40 stations. Under the reported measures, the source–station discrepancy is generally larger than the selection–source discrepancy. This comparison does not separately identify contributions from reanalysis error, station–grid support differences or their interaction with month selection.
- **Annual hours.** Median absolute differences in annual exposure hours to the stations are 25–55 %, similar to the other typical years.

The products differ in source data, period and support, so the counts do not rank selection algorithms.

4.7 Screening applications

In version 2, 194 of 196 screening outputs lie within the range of the 20 actual years (version 1: 195). Both exceptions are duration-curve distances closer to the pooled curve than every actual year: Quito (0.56 °C, unchanged) and Dubai (0.85 → 0.83 °C, below the smallest actual-year value of 0.84 °C). Smoothing changes 13 of 196 percentile positions, by at most 15 points.

Table 7. Screening applications, released version 2 and unsmoothed version 1.

Application	Quantity	v2	v1
A1–A4	Outputs within the actual-year range	194 of 196	195 of 196
A1	Percentile of the 70 temperature quantiles: median (range)	50 (10–75)	50 (10–75)
A2	Degree-hour outputs within the actual-year range	28 of 28	28 of 28
A3	Locations whose time-of-wetness level equals that of all 20 actual years	11 of 14	11 of 14
A4	Percentile range of near-saturation hours	25–60	25–60

The following holds for both versions:

- **Temperature duration curves:** quantiles lie between the 10th and 75th percentile of the actual years, with a median at the 50th.
- **Heating and cooling degree hours:** within the actual-year range at every location.
- **Calculated time-of-wetness levels:** equal those of all 20 actual years at 11 locations.
- **Near-saturation hours:** between the 25th and 60th percentile.
- **Rare cold counts:** some are zero in the composite year although positive in some actual years, for example Dubai ≤ 7 °C. Rare extremes are not preserved.

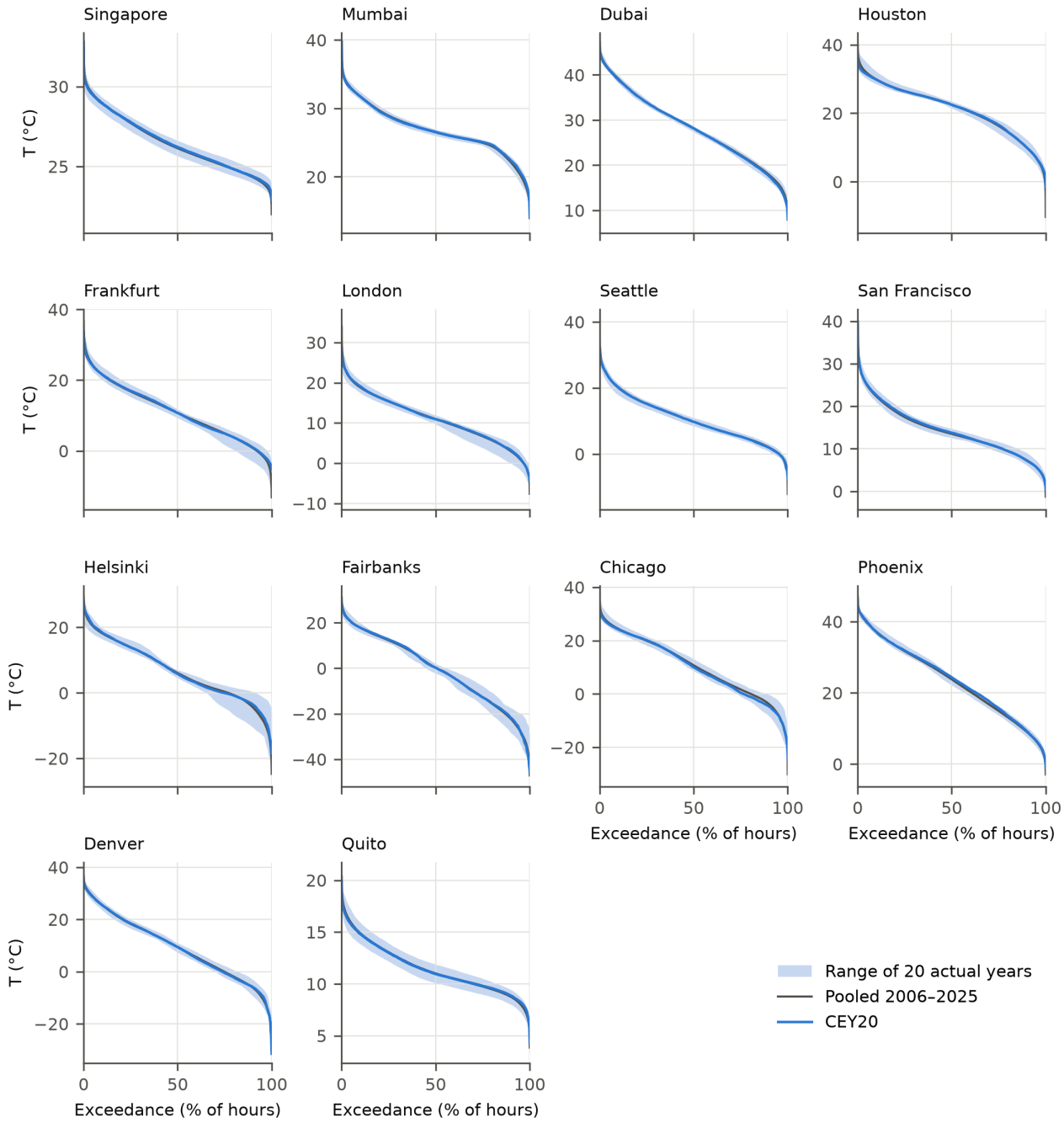


Figure 2. Hourly temperature duration curves of the released version 2 (blue) at the 14 locations, with the pooled 2006–2025 curve (grey) and the range of the 20 actual years at each exceedance level (shaded).

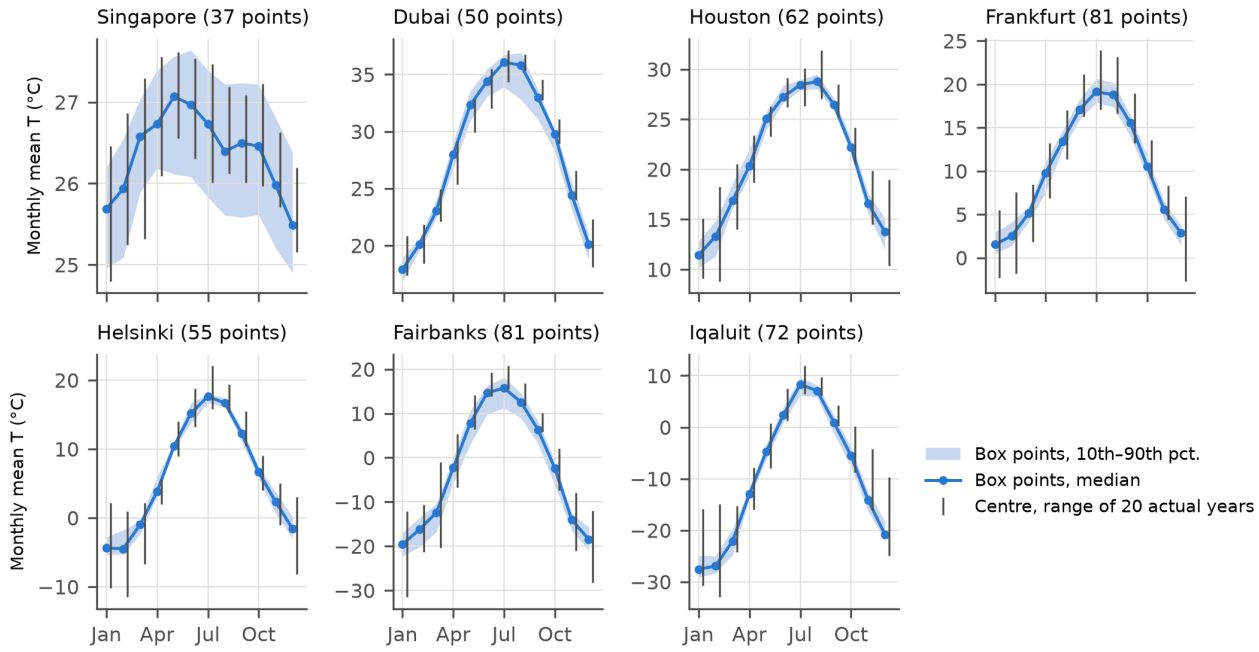


Figure 3. Monthly mean temperature of the released version 2 across the land points of 2° × 2° boxes around seven region centres: median (line) and 10th–90th percentile (shaded) of the box points. Vertical bars: range of the 20 actual years at the centre point. Number of box points in the panel titles. Box points can have different selected source years, so the envelope is not a simultaneous regional weather field. The spatial percentiles and the centre's interannual range describe different populations and are not uncertainty intervals.

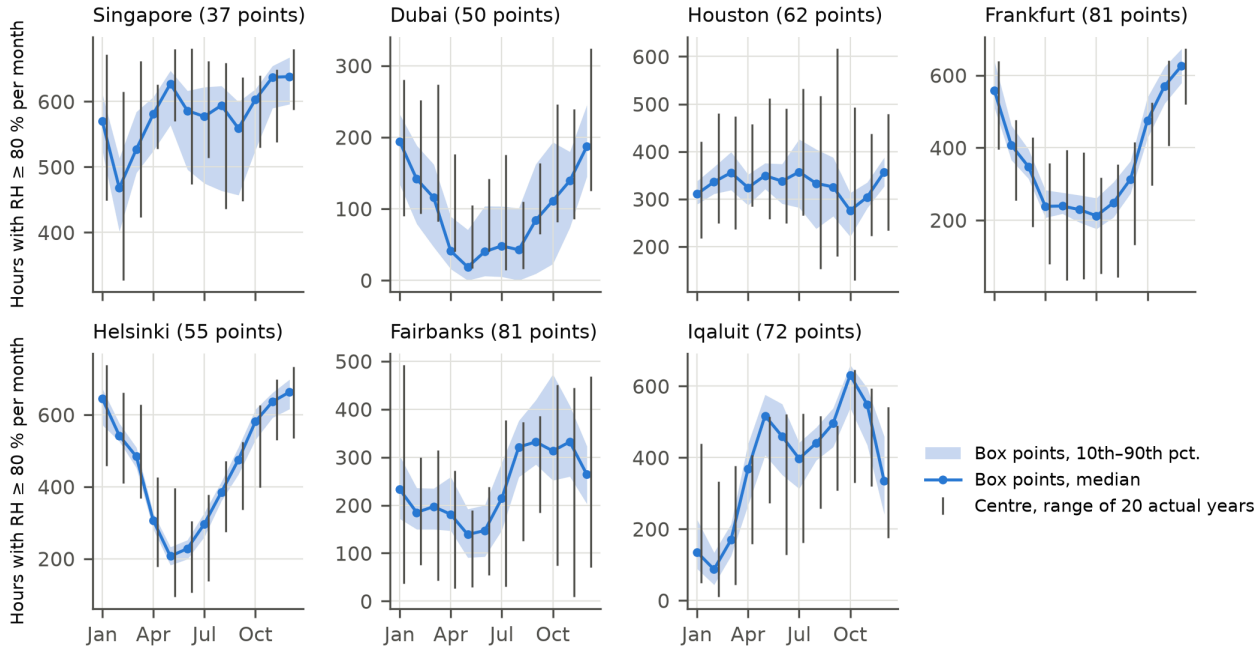


Figure 4. As Figure 3, for the monthly hours with RH ≥ 80 %. The corresponding figure for monthly mean RH is in the study package.

4.8 Baseline: the unsmoothed version 1

The frozen version-1 construction failed the pre-registered targets. Checks outside tolerance comprised 9 of 42 annual exposure checks, 60 of 168 monthly temperature checks and 14 of 168 monthly humidity checks. All nine failed annual checks underestimate the reference and occur at Phoenix, Denver, Fairbanks and Chicago. Across all 42 annual checks, 25 underestimate and 17 overestimate the reference, so the direction is not uniform.

The version-1 month joins show large synthetic discontinuities, which motivated the smoothing:

- **Cross-year inner boundaries.** Hourly changes exceed the reference 99th percentile in 68 of 150 checks for T, 85 of 150 for Td and 55 of 150 for RH.
- **Same-source-year inner boundaries:** 0 of 4 for every variable.
- **December–January wrap:** 7, 11 and 4 of 14 for T, Td and RH.
- **Largest step:** 33.7 °C in T at Fairbanks, January to February.

The sensitivity, LOYO and FS analyses (Sections 4.3 and 4.5) were run on this construction only. All version-1 values are paired with version 2 in Tables 3–5 and 7 and in Appendix A.

5. Discussion

5.1 What the construction achieves

For the frozen 14 locations, 2006–2025 source period, UTC/365-day calendar and builder humidity convention, the released version and the unsmoothed construction show agreement on several evaluated quantities.

- The binned joint T/RH distribution is closer to the pooled reference than every individual source year at 9 of 14 locations.
- Humid-spell and drying-gap statistics fall within the actual-year range in 195 of 196 checks, as do 194 of 196 screening outputs in version 2 (195 in version 1).
- Monthly mean humidity is within 2 percentage points of the reference in 153 of 168 location-months (154 in version 1).

In the same-data comparison of unsmoothed constructions, CEY20 has more annual exposure-hour and monthly humidity checks within tolerance than either tested FS-based selection. Both FS-based selections have more monthly temperature checks within tolerance. These results describe agreement on the evaluated quantities.

5.2 Where deviations arise

The trade-off. Selecting one actual year for each month does not generally guarantee simultaneous agreement with the 20-year means of several correlated statistics; the score trades them against each other.

Where it shows. The annual exposure deviations concentrate at two arid or semi-arid locations (Phoenix, Denver) and at two continental locations (Fairbanks, Chicago). Monthly temperature deviates most at Fairbanks and Helsinki. One possible reason is that a single month's choice weighs more where humid hours cluster in few months or where interannual variability is large. This was not tested, and 14 locations do not establish climate-wide patterns.

Two documented properties are relevant without establishing a mechanism.

- **Absolute scales, relative tolerance.** The count features enter the score in absolute hours with fixed scales (180, 120 and 120 h), whereas the annual tolerance is relative. A given absolute deviation therefore carries the same score penalty at every location but is a larger relative deviation where annual counts are small.
- **Mean versus typical year.** In a post-hoc exploratory analysis outside the frozen protocol (Okley, 2026a, Section 4.3), the selected annual counts of the unsmoothed construction were compared with the sum of the 12 monthly medians instead of the 20-year mean. 39 of 42 lie within ±5 % of that sum, compared with 33 of 42 within ±5 % of the mean. At all nine checks outside tolerance, the sum of monthly medians is below the mean, by 2.0 % to 21.0 %.
- At eight of these nine checks the selected count is closer in absolute hours to the sum of monthly medians than to the mean. Denver RH ≥ 90 % is the exception (26.5 h versus 23.7 h).
- The analysis was not specified in advance, uses the archive the months were selected from, and involves quantities that are also selection features. It describes the selected years and does not establish a mechanism.

Possible extensions, not evaluated here:

- an absolute-hour floor for rare events;
- climate-dependent scales;
- secondary ranking as in TMY3.

5.3 Month interfaces

Cross-year joins are inherent to any typical-month construction. In the unsmoothed construction they produced large hourly steps. The released version applies a TMY3-style 6-hour ramp:

- **Boundary steps.** Under the primary reference, no boundary step at a cross-year inner boundary exceeds the 99th percentile of natural hourly changes in the released version.
- **Window maxima.** The largest change within the 12-hour window still exceeds that percentile at 8–26 % of these boundaries, depending on the variable, and more often under the stricter 23→00 UTC reference.
- **Effect on results.** Annual tolerance counts are unchanged; one monthly temperature check enters tolerance and one humidity check leaves it. Percentile positions change for 30 of 196 spell and gap statistics and for 13 of 196 application outputs, and one further application output lies outside the actual-year range, closer to the pooled climate.

Smoothed hours are synthetic. Applications that depend on hourly dynamics near month ends should take this into account. The evaluation assesses a remedy developed after the version-1 outcomes were observed at the same frozen locations; it does not establish independent validation, climate-wide representativeness or production readiness.

5.4 Intended use

CEY20 is intended for exploratory moisture and thermal exposure screening across locations using a consistent global method. It is not intended for:

- design values or extremes analysis;

- energy or solar simulation, since it contains no radiation or wind;
- statements of conformity with ISO 9223, ISO 15927-4 or EN 14825.

6. Limitations

- **Sample and source.** 14 locations, one reanalysis at 0.25°. Coastal, urban and mountain microclimates are not resolved.
- **In-sample.** The evaluation uses the archive the selection was drawn from, and the tolerances overlap the selection features.
- **Not fully blind.** Eight locations were inspected beforehand, and the version-2 re-evaluation was declared after the version-1 results were known, with prior development evidence on version 2 (Section 3.1). It is not an independent validation of the smoothing.
- **Parameters.** The weights and scales are expert-set, not calibrated.
- **Conventions.** UTC days; humidity is relative to liquid water below 0 °C.
- **Unsmoothed analyses.** Sensitivity, LOYO and the FS comparison concern the unsmoothed selection.
- **Independence.** No uncertainty intervals are given for the counts, and the checks are not independent.

7. Data and code availability

The study package is available at https://github.com/VWOakley/cey20-study and archived as version 1.0.0 at https://doi.org/10.5281/zenodo.24091411 (Okley, 2026c; code MIT, documents and tables CC BY 4.0).

- **Code.** It contains the month-selection code (`build_global_cey20_landpoint_dataset.py`), the month-interface smoothing code of version 2 and all study scripts. These are byte-identical to the code pinned before each run.
- **Study record.** Protocol, specifications, freeze records, pins, amendments, reviews of the amendment, and all result tables.
- **Inputs.** ERA5-Land hourly data are available from the Copernicus Climate Data Store (Muñoz-Sabater, 2019). The analyses read monthly land-point files derived from these data. The study package lists their SHA-256 checksums (`study/03-freeze-input-sha256.json`), which document the files used; files rebuilt from a new download are not expected to be byte-identical.

Declarations

Use of AI tools. AI coding and writing assistants (Anthropic Claude, OpenAI Codex, GitHub Copilot) were used under the author's direction for software development, scripted analysis runs, internal code and method consistency checks, and drafting. After using these tools, the author reviewed and edited the content as needed and takes full responsibility for the content of the manuscript. AI tools are not authors.

Competing interests. The author develops and operates Climetry, which provides CEY20 data free of charge.

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ERA5-Land: contains modified Copernicus Climate Change Service information (2026). Neither the European Commission nor ECMWF is responsible for any use that may be made of the Copernicus information or data it contains.

Appendix A. Checks outside the tolerances

Table A1. Annual exposure checks outside ±5 % (H in hours per year). The same nine checks lie outside tolerance in both versions.

Location	Metric	H_{sel} v1	H_{sel} v2	H_{ref}	Relative difference v1	Relative difference v2
Phoenix	RH ≥ 80 %	404	397	511.95	−21.1 %	−22.5 %
Phoenix	D ≤ 2 °C	188	183	229.5	−18.1 %	−20.3 %
Phoenix	RH ≥ 90 %	112	108	136.05	−17.7 %	−20.6 %
Fairbanks	RH ≥ 90 %	619	614	723.85	−14.5 %	−15.2 %
Denver	RH ≥ 80 %	1136	1140	1305.15	−13.0 %	−12.7 %
Denver	D ≤ 2 °C	610	610	685.1	−11.0 %	−11.0 %
Fairbanks	D ≤ 2 °C	1173	1177	1308.7	−10.4 %	−10.1 %
Chicago	RH ≥ 90 %	1007	1002	1086.1	−7.3 %	−7.7 %
Denver	RH ≥ 90 %	421	421	444.7	−5.3 %	−5.3 %

Monthly checks (version 1). Temperature lies outside ±0.5 °C in 60 location-months:

Location	Location-months
Fairbanks	9
Helsinki	8
Houston, Chicago, Phoenix, Denver	6 each
Frankfurt, San Francisco	5 each
Seattle, London	3 each
Dubai	2
Mumbai	1
Singapore, Quito	0

The largest deviations are +2.12 °C (Phoenix, October), +2.02 °C (Helsinki, July) and −1.86 °C (Chicago, December). RH lies outside ±2 pp in 14 location-months; the largest deviations are +4.22 pp (Phoenix, February) and −4.09 pp (Denver, February). Appendix A1 lists all nine annual failures; Appendix A2 lists all 60 monthly temperature failures and all 14 monthly humidity failures individually. Version 2 differs in two location-months, both at Chicago: May temperature is within tolerance (+0.49 °C) and March humidity is outside it (+2.07 pp).

Appendix A2. All monthly checks outside tolerance in either version (deviation = selected minus 20-year reference; "(within)" marks a deviation inside the tolerance in that version).

Table A2a. Monthly mean temperature outside ±0.5 °C in either version (v1: 60 of 168; v2: 59 of 168).

Location	Month	Selected year	Deviation v1	Deviation v2
Dubai	Jan	2007	−1.29 °C	−1.30 °C

Location	Month	Selected year	Deviation v1	Deviation v2
Houston	Jan	2021	+0.56 °C	+0.58 °C
Frankfurt	Jan	2012	+0.80 °C	+0.78 °C
San Francisco	Jan	2021	+0.72 °C	+0.70 °C
Helsinki	Jan	2022	+0.69 °C	+0.72 °C
Fairbanks	Jan	2007	+0.90 °C	+0.84 °C
Chicago	Jan	2015	−1.59 °C	−1.59 °C
Phoenix	Jan	2022	+0.59 °C	+0.57 °C
Denver	Jan	2017	+0.61 °C	+0.60 °C
Seattle	Feb	2025	−0.85 °C	−0.87 °C
Fairbanks	Feb	2024	+0.87 °C	+1.00 °C
Phoenix	Feb	2007	−0.61 °C	−0.58 °C
Dubai	Mar	2011	−0.55 °C	−0.55 °C
Houston	Mar	2009	−0.79 °C	−0.78 °C
London	Mar	2010	−0.67 °C	−0.66 °C
Seattle	Mar	2021	−0.58 °C	−0.57 °C
San Francisco	Mar	2009	−0.51 °C	−0.55 °C
Helsinki	Mar	2023	−0.54 °C	−0.52 °C
Fairbanks	Mar	2013	−1.05 °C	−1.08 °C
Chicago	Mar	2011	−1.82 °C	−1.81 °C
Phoenix	Mar	2011	+0.54 °C	+0.53 °C
Denver	Mar	2006	−1.01 °C	−1.07 °C
Frankfurt	Apr	2012	−1.18 °C	−1.18 °C
San Francisco	Apr	2023	−1.16 °C	−1.13 °C
Helsinki	Apr	2015	+0.64 °C	+0.62 °C
Fairbanks	Apr	2008	−0.73 °C	−0.69 °C
Denver	Apr	2025	+0.74 °C	+0.74 °C
Houston	May	2018	+0.80 °C	+0.80 °C
Helsinki	May	2011	−0.86 °C	−0.87 °C
Fairbanks	May	2019	+1.63 °C	+1.61 °C
Chicago	May	2013	+0.55 °C	+0.49 °C (within)
Houston	Jun	2020	−0.86 °C	−0.86 °C
Frankfurt	Jun	2018	+0.59 °C	+0.56 °C
London	Jun	2009	−0.58 °C	−0.59 °C
Helsinki	Jun	2010	−1.19 °C	−1.16 °C
Fairbanks	Jun	2011	−0.57 °C	−0.57 °C
Phoenix	Jun	2006	+1.00 °C	+0.99 °C
Denver	Jun	2014	−0.84 °C	−0.86 °C
Frankfurt	Jul	2013	+0.54 °C	+0.55 °C
London	Jul	2014	+0.83 °C	+0.83 °C
Seattle	Jul	2021	+1.16 °C	+1.15 °C
Helsinki	Jul	2011	+2.02 °C	+2.02 °C

Location	Month	Selected year	Deviation v1	Deviation v2
Houston	Aug	2014	−0.54 °C	−0.54 °C
Chicago	Aug	2025	−0.62 °C	−0.59 °C
San Francisco	Sep	2022	+0.85 °C	+0.85 °C
Helsinki	Sep	2020	+0.65 °C	+0.66 °C
Frankfurt	Oct	2013	+0.56 °C	+0.57 °C
Fairbanks	Oct	2011	+0.55 °C	+0.55 °C
Phoenix	Oct	2016	+2.12 °C	+2.12 °C
Mumbai	Nov	2023	+1.00 °C	+0.99 °C
San Francisco	Nov	2014	+1.17 °C	+1.20 °C
Fairbanks	Nov	2020	−0.61 °C	−0.58 °C
Chicago	Nov	2025	+0.63 °C	+0.64 °C
Phoenix	Nov	2023	+1.24 °C	+1.26 °C
Denver	Nov	2010	−0.97 °C	−0.96 °C
Houston	Dec	2007	+0.72 °C	+0.69 °C
Helsinki	Dec	2018	−0.66 °C	−0.67 °C
Fairbanks	Dec	2019	−0.59 °C	−0.64 °C
Chicago	Dec	2025	−1.86 °C	−1.88 °C
Denver	Dec	2022	−0.72 °C	−0.72 °C

Table A2b. Monthly mean RH outside ±2 pp in either version (v1: 14 of 168; v2: 15 of 168).

Location	Month	Selected year	Deviation v1	Deviation v2
San Francisco	Jan	2021	−2.25 pp	−2.21 pp
Phoenix	Feb	2007	+4.22 pp	+4.00 pp
Denver	Feb	2013	−4.09 pp	−4.31 pp
Chicago	Mar	2011	+1.98 pp (within)	+2.07 pp
Phoenix	Mar	2011	−2.88 pp	−2.95 pp
Denver	Mar	2006	−2.77 pp	−2.63 pp
Dubai	Jun	2023	+2.58 pp	+2.52 pp
Frankfurt	Jul	2013	+2.76 pp	+2.63 pp
Dubai	Aug	2007	+2.22 pp	+2.32 pp
Phoenix	Sep	2023	−2.83 pp	−2.79 pp
Phoenix	Oct	2016	−2.05 pp	−2.14 pp
Fairbanks	Nov	2020	+3.34 pp	+3.37 pp
Mumbai	Dec	2024	+2.26 pp	+2.25 pp
San Francisco	Dec	2012	+2.98 pp	+2.98 pp
Denver	Dec	2022	−3.33 pp	−3.33 pp

Appendix B. Locations

Table B1. Requested coordinates, assigned ERA5-Land grid cell and great-circle distance.

Location	Requested lat	Requested lon	Grid lat	Grid lon	Distance (km)
Singapore	1.3521	103.8198	1.50	103.75	18.18
Mumbai	19.0760	72.8777	19.00	73.00	15.38
Dubai	25.2048	55.2708	25.00	55.25	22.87
Houston	29.7604	−95.3698	29.75	−95.25	11.62
Frankfurt	50.1109	8.6821	50.00	8.75	13.25
London	51.5074	−0.1278	51.50	−0.25	8.50
Seattle	47.6062	−122.3321	47.50	−122.25	13.32
San Francisco	37.7749	−122.4194	37.75	−122.25	15.15
Helsinki	60.1699	24.9384	60.25	25.00	9.53
Fairbanks	64.8378	−147.7164	64.75	−147.75	9.89
Chicago	41.8781	−87.6298	42.00	−87.75	16.81
Phoenix	33.4484	−112.0740	33.50	−112.00	8.95
Denver	39.7392	−104.9903	39.75	−105.00	1.46
Quito	−0.1807	−78.4678	−0.25	−78.50	8.50

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