Supplementary Materials for

The Developmental Morphospace of Wildfire

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Supplementary Methods

S1. Source observations and Fire VASE construction

Fire VASE histories were constructed from FIRED event and observation products derived from the MODIS burned-area record [1, 2, 3]. Event-level records identify the fire and report its ignition and final dates, duration, final mapped area, and final geometry. Associated observations provide an event identifier, observation date, event-day field, newly mapped burned area, and cumulative mapped burned area. The analyzed archive contains 278,569 events and 626,102 observed slices from 2 November 2000 through 1 May 2021.

Observations were ordered within each fire by date and event-day field. We use *observed developmental slice* because adjacency in this ordered record has not yet been demonstrated to represent uninterrupted calendar days for every event. Negative mapped-area increments were set to zero. For fire i and ordered slice j, let g_{ij} denote the resulting nonnegative mapped-area increment. Cumulative observed area was

$$A_{ij} = \sum_{k=1}^{j} g_{ik}. \tag{S1}$$

For a positive-area fire with final observed slice T_i, normalized VASE width was

$$w_i(t_j) = \sqrt{\frac{A_{ij}}{A_{iT_i}}}. \tag{S2}$$

Normalized width lies between 0 and 1 and terminates at 1. The square root converts relative area to a radius-like dimension: for an equal-area disk, radius is proportional to the square root of area. A VASE therefore records the allocation of cumulative area through the observed history. It does not encode geographic perimeter shape, displacement, or direction of spread.

For fires with more than one observed slice, relative developmental time was scaled from 0 at the first observation to 1 at the final observation. One-slice events were placed at 0.5. This normalization aligns fires by position in their observed sequence without asserting equal calendar-time intervals between slices. One-slice events retain an observed outcome but contain no within-event developmental trajectory. Their influence on the full morphospace is evaluated explicitly in Supplementary Methods S4.

S2. Developmental feature construction

Each fire was described with scalar developmental summaries and interpolated profiles (Table S2). These features quantify when mapped growth occurred, how concentrated or evenly distributed it was, whether major-growth periods recurred, and how normalized width changed through the observed sequence.

Peak timing was the relative developmental position of maximum observed growth. Front-loaded fraction was the share of final observed area accumulated by relative time 0.5; late-growth fraction was the share added after relative time 0.75. Terminal taper was the final observed increment divided by maximum observed slice growth.

A slice belonged to a major-growth period when its mapped-area increment exceeded the maximum of the within-fire 75th percentile, 25% of maximum observed growth, and a small positive floor of [CODEX: insert pulse threshold floor and units]. Pulse count was the number of transitions into major-growth periods. Reactivation count was pulse count minus one, bounded below by zero.

Positive observed growth fractions were normalized within fire to sum to one [CODEX: verify implementation and report reconciliation with catalog final area]. Growth entropy was then calculated as

$$H_i = -\frac{\sum_j p_{ij} \log p_{ij}}{\log n_i}, \tag{S3}$$

where p_{ij} is the normalized positive growth fraction and n_i is the number of observed slices [4]. Developmental velocity and acceleration were the mean absolute first and second differences of normalized

VASE width. Their interpretation as temporal rates depends on observation spacing. Adjacent slices were separated by [CODEX: insert distribution of calendar gaps and proportion separated by one day].

Normalized VASE width and normalized incremental growth were linearly interpolated to 11 common positions in relative developmental time. These profiles retain the trajectory beyond scalar summaries. Group-level composite VASEs used 41 positions and display median width with an interquartile envelope.

The current feature matrix also contains final area, recorded duration, observation count, slenderness, and an absolute growth-rate field labeled peak growth. The operational formula for that field is [CODEX: verify and insert formula; distinguish peak from mean growth]. Complete provenance for every feature is reported in Table S2.

S3. Full multivariate morphospace

The primary morphospace in the current manuscript combines normalized developmental summaries and profiles with absolute event attributes. Final area, recorded duration, the growth-rate field labeled peak growth, and slenderness were log transformed. Missing values were replaced with the median of the corresponding feature. All features were centered and scaled to unit variance before principal component analysis by singular value decomposition [5].

The analysis retained the first five principal-component scores as continuous morphospace coordinates. The full analysis contained [CODEX: insert N fires entering PCA] fires and [CODEX: insert N features] features. PC1 through PC5 explained [CODEX: insert full-PCA variance percentages] of total standardized variance, with cumulative explained variance of [CODEX: insert cumulative variance PC1–PC5]. Leading loadings and feature-family contributions are reported in Tables S5 and S6.

Weather variables were attached only after this coordinate system was estimated. The full morphospace is therefore independent of the weather table but not independent of conventional event attributes. Descriptive neighborhoods were assigned to make regions of the continuous space interpretable; they were not inferred as statistically discrete classes. The labels were single flash, skinny persistent, multi-pulse complex, late surge, front-loaded plateau, and compact steady. Continuous traits and principal-component coordinates, rather than these labels, were used as model responses.

S4. Robustness of developmental morphology to observation depth

Nearly 60% of the full FIRED population lies in the single-flash neighborhood. Because a one-slice fire contains no internal trajectory, the full population may emphasize differences between minimally and repeatedly observed events. Observation-depth sensitivity asks whether the principal developmental organization persists among fires for which progressively more of the growth history is observed.

We refitted the complete preprocessing and PCA independently for fires with at least 2, 3, 5, and 10 observed slices. Each threshold therefore received its own median imputation, feature scaling, covariance structure, loadings, and scores. Fires were not merely filtered from the coordinates of the full-population

PCA. The retained sample at each threshold was [CODEX: insert N2], [CODEX: insert N3], [CODEX: insert N5], and [CODEX: insert N10] events, respectively.

For every refitted space, we compared:

1. variance explained by the first five components;
2. leading positive and negative loadings;
3. aggregate contribution of scalar, profile, timing, pulse, endpoint, and observation-depth feature families;
4. whether timing, front-loading or concentration, persistence, late growth, and pulsing remained recognizable directions;
5. representative VASE histories at comparable locations along the leading axes; and
6. quantitative correspondence between spaces.

Axis correspondence was assessed with [CODEX: insert alignment method, such as signed score correlation, Procrustes alignment, loading-vector cosine similarity, or subspace angle, with justification]. Because PCA axis signs are arbitrary and component order may change, comparison used sign- and permutation-aware alignment. Stability was summarized by [CODEX: insert statistic and uncertainty or resampling procedure]. Figure S1 and Tables S5–S7 report the results.

The purpose of this sensitivity is not to select the threshold producing the clearest figure. It tests whether the developmental gradients identified in the full population persist when increasingly well-observed histories define the coordinate system.

S5. Developmental morphospace independent of absolute event attributes

The full morphospace is useful as a multivariate description of fires, but it cannot establish that its major axes arise from developmental form alone because final area, duration, observation count, absolute growth, and slenderness contribute directly. We therefore constructed a shape-only developmental morphospace to ask whether coherent organization remains after conventional endpoint and absolute-scale information is removed.

The excluded feature set comprised final area, recorded duration, observation count, the absolute growth-rate field, slenderness, and [CODEX: insert any additional absolute-scale or observation-depth features identified by the audit]. The retained set comprised normalized VASE width profiles, normalized growth profiles, peak timing, front-loaded fraction, late-growth fraction, terminal taper, normalized growth entropy, pulse and reactivation structure, and normalized developmental velocity and acceleration. Features found to encode observation count or absolute event scale indirectly were [CODEX: identify exclusions or state none after audit].

The shape-only features were reimputed, centered, and scaled within the analysis population, and a new PCA was fitted rather than projecting onto the loadings of the full representation. The shape-only PCA contained [CODEX: insert N fires] fires and [CODEX: insert N retained features]. Its first five components explained [CODEX: insert shape-only variance percentages], with cumulative variance of [CODEX: insert cumulative variance PC1–PC5].

We compared the full and shape-only spaces using aligned score and loading relationships, feature-family contributions, representative VASEs, and neighborhood correspondence where informative. Final area, duration, observation count, and centroid weather were then projected as external attributes onto the shape-only space. We also repeated the principal weather overlays and mismatch summaries using the shape-only coordinates [CODEX: insert exact analyses repeated]. Figure S2 and Tables S5–S7 report whether recognizable developmental structure persisted after removal of endpoint information.

S6. Weather attribution and environmental summaries

Daily gridMET fields supplied the first environmental layer projected onto the observed histories [6]. For each event, the final mapped geometry was transformed to an equal-area coordinate system, its centroid was calculated, and the location was transformed back to longitude and latitude. Weather for every observed date was extracted from the nearest gridMET cell to this fixed centroid. These are retrospective final-event-centroid exposures rather than contemporaneous active-edge conditions.

The attributed variables were maximum and minimum temperature, vapor pressure deficit (VPD), wind speed, precipitation, maximum and minimum relative humidity, specific humidity, 100-hour and 1000-hour dead fuel moisture, energy release component, burning index, reference evapotranspiration, potential evapotranspiration, and solar radiation (Table S3). Complete weather histories were available for 237,235 events [CODEX: verify final N after all revisions].

For every variable, event-level summaries included the mean, observed minimum and maximum, and means within early, middle, and late thirds of relative developmental time. Region–month anomalies subtracted the median among fires in the same broad region and calendar month; these are contrasts within the fire population rather than independent climate normals. Extreme-slice fractions used the 90th percentile for hot, high-VPD, windy, and high-ERC conditions, the 10th percentile for dry 1000-hour fuel moisture, and precipitation greater than zero for wet conditions. Perimeter, newly burned area, cumulative burned area, and perimeter-extension exposures were retained as supplemental products but were not the basis of the population results reported here.

S7. Event-level predictive models

Spearman correlations related weather summaries to front-loaded fraction, late-growth fraction, terminal taper, growth entropy, pulse count, reactivation count, peak timing, recorded duration, final area, and the first morphospace coordinate. Complete coefficients and sample sizes are reported in Figure S3 and [CODEX: insert machine-readable table identifier].

Ridge-regularized linear models with penalty $\alpha = 1.0$ compared core atmospheric conditions, moisture and humidity, fire-danger and energy variables, combined event summaries, region–season anomalies, extreme-slice fractions, and weather resolved across early, middle, and late development (Table S4). Predictors were standardized using only each training fold and then transformed with the corresponding training estimates in held-out data.

Random-fire folds served as an interpolation diagnostic. Blocked tests held out broad year groups, broad geographic regions, or hashed region–year combinations. Held-out R^2 was calculated after concatenating predictions across folds and comparing them with the mean of the held-out response. Predictor groups were compared on [CODEX: insert common-cohort rule and N]; sensitivity to maximum VPD and record length was assessed by [CODEX: insert ablation and duration/observation-count adjustment]. Response-specific performance and block-to-block uncertainty are reported in Figure S3.

S8. State-dependent subsequent-growth models

The state analysis asked whether weather at an observed slice had different associations with growth in the subsequent retained slice depending on current fire state. Within fire, growth from the next retained slice was shifted backward and transformed as $\log[1 + \text{area (km}^2)]$. This response conditions on another retained observation. The distribution of calendar intervals represented by the shift was [CODEX: insert interval distribution and percentage equal to one day]; treatment of terminal observations was [CODEX: insert rule and excluded N].

Current state was represented by relative developmental position, current mapped growth, cumulative observed area, and the change in growth from the previous retained slice. Models compared weather only, state only, additive weather plus state, and weather–state interactions. Interactions paired each core weather variable with developmental position, current growth, and current cumulative area. The principal comparison was the incremental information supplied by weather and interactions beyond the autoregressive state-only baseline.

The displayed VPD-by-current-growth relationship was evaluated with [CODEX: insert uncertainty procedure]. Empirical support was quantified by [CODEX: insert bin counts, density estimate, convex-hull rule, or other support diagnostic] so that fitted curves could be distinguished as interpolation or extrapolation. These diagnostics are reported in Figure S4.

S9. Weather–morphology mismatch analysis

Mismatch analysis asked whether fires close in centroid-weather space were necessarily close in developmental space, and vice versa. Weather variables and morphospace coordinates were standardized before distance calculation. Candidate pairs were selected by [CODEX: insert final matching algorithm, candidate-set size, calipers, and partner-reuse rule]. Selection used fixed seeds and deterministic scoring rules.

For each displayed pair, the recorded information comprised event identifiers, observation count, duration, final area, region and dates, standardized weather distance, standardized morphology distance, and the variables entering each distance [CODEX: insert table or machine-readable output identifier]. Mismatch structure was repeated for [CODEX: insert multivariate/shape-only and observation-threshold spaces evaluated]. A null or permutation comparison used [CODEX: insert method and repetitions]. The resulting prevalence or diagnostic rate was [CODEX: insert result, or state that the design supports existence rather than prevalence].

S10. Reproducibility and computational provenance

The analysis is organized as a versioned sequence from source observations through derived histories, statistical summaries, and figures. Manifests record the identity and checksum of inputs and outputs. Fixed seeds control sampling, fold assignment, and representative-fire selection. Derived statistics are written before plotting so numerical claims can be checked independently of rendering.

The analysis used repository revision [CODEX: insert commit SHA], data-release identifier [CODEX: insert release or archive DOI], analysis configuration [CODEX: insert configuration identifier], and software environment [CODEX: insert environment lock or container identifier]. The regeneration commands were [CODEX: insert command sequence]. Machine-readable outputs corresponding to Tables S5–S7 and Figs. S1–S4 are archived at [CODEX: insert paths or archival identifiers].

Supplementary Results

S11. Observation-depth robustness

The full population contained 278,569 events, of which [CODEX: insert N and percentage with exactly one slice] had one observed slice. After restricting the population to fires with at least two observed slices, [CODEX: insert N2] events remained. Corresponding sample sizes at thresholds of three, five, and ten slices were [CODEX: insert N3], [CODEX: insert N5], and [CODEX: insert N10], respectively (Fig. S1A; Table S5).

Across these independently refitted spaces, the leading developmental gradients [CODEX: describe persistence, rotation, splitting, or loss without presupposing direction]. PC1 accounted for [CODEX: insert range]

Quantitative alignment between the full-population and threshold-specific spaces was [CODEX: insert alignment results with uncertainty]. The greatest change occurred at [CODEX: insert threshold or state none], where [CODEX: describe structural change]. Representative VASEs [CODEX: describe whether they retained comparable interpretation across thresholds]. Feature-family contributions [CODEX: describe changes as short records were removed].

These results indicate that the observed developmental gradients [CODEX: insert balanced conclusion: persist, partly persist, or depend strongly on observation depth]. The manuscript interpretation is therefore [CODEX: insert resulting scope of claim].

S12. Shape-only morphospace robustness

The shape-only analysis retained [CODEX: insert N fires and population definition] and [CODEX: insert N features] normalized developmental features. PC1 through PC5 explained [CODEX: insert percentages] of standardized variance, compared with [CODEX: insert full-space percentages] in the full multivariate representation (Table S5).

After removal of final area, duration, observation count, absolute growth, slenderness, and [CODEX: insert any other excluded features], the leading axes [CODEX: describe persistence or reorganization]. Shape-only PC1 was dominated by [CODEX: insert loadings and interpretation]; PC2 was dominated by [CODEX: insert loadings and interpretation]. Alignment with the original space was [CODEX: insert statistic], indicating [CODEX: interpret correspondence without overstating].

Representative histories across the shape-only axes [CODEX: describe recognizable forms or loss of interpretability]. When final area and duration were projected as external attributes, they [CODEX: describe pattern]. Centroid-weather gradients [CODEX: describe similarity or change], and mismatch structure [CODEX: describe persistence or change].

The shape-only results therefore [CODEX: answer whether coherent developmental organization remains when endpoint information is removed]. This outcome [CODEX: state how the distinction between normalized VASE morphology and the full multivariate fire representation should be expressed in the manuscript].

S13. Environmental model diagnostics

The complete weather–development correlation matrix is shown in Figure S3A. The strongest positive associations were [CODEX: insert variables, responses, coefficients, and N]; the strongest negative associations were [CODEX: insert variables, responses, coefficients, and N]. Associations after accounting for region, season or month, year, duration, and observation count [CODEX: insert result and method].

Response-specific held-out performance is shown in Figure S3B–D. On the common comparison cohort of [CODEX: insert N], the core, moisture, fire-danger, comprehensive, anomaly, extreme, and time-resolved predictor groups achieved [CODEX: insert concise performance summary]. The maximum-VPD ablation [CODEX: insert result]; adjustment for duration or observation count [CODEX: insert result]. These diagnostics [CODEX: state whether the current event-level interpretation is strengthened, weakened, or unchanged].

S14. State-interaction diagnostics

The state-model analysis contained [CODEX: insert N transitions from N fires]. Of these transitions, [CODEX: insert N and percentage] represented exactly one calendar day. Weather-only, state-only, additive, and interaction models achieved held-out R^2 of [CODEX: insert response-specific or summarized values] under [CODEX: insert validation schemes].

The VPD-by-current-growth interaction was supported by [CODEX: insert uncertainty summary]. Observations across the displayed domain were [CODEX: describe sample support]; the high-growth, high-VPD portion contained [CODEX: insert N or effective support]. The displayed relationship therefore represents [CODEX: interpolation, partial extrapolation, or mixed support]. Weather–state interactions added [CODEX: insert incremental performance] beyond the state-only baseline.

These results support the interpretation that [CODEX: insert calibrated conclusion about state dependence], while not supporting [CODEX: insert causal or forecasting claims that remain excluded].

S15. Mismatch diagnostics

The final matching procedure identified [CODEX: insert N qualifying weather-matched pairs] and [CODEX: insert N qualifying morphology-matched pairs] under the declared calipers. Partner reuse was [CODEX: insert result], and null or permutation comparisons showed [CODEX: insert result].

Mismatch structure across the full, multi-observation, and shape-only spaces [CODEX: describe robustness]. The exemplar pairs used in the main figure were [CODEX: retained or replaced, with reason]. Their event characteristics and standardized distances are reported in [CODEX: insert table or machine-readable output].

The analysis demonstrates [CODEX: state whether it supports the existence, frequency, or both of reciprocal mismatch]. It does not identify which omitted environmental, spatial, management, or observational process produced any individual mismatch.

Supplementary Figures

[CODEX: Figure S1]

Insert the validated repository-generated figure here.

Figure S1: **Robustness of developmental morphology to observation depth.** (A) Number and percentage of fires retained when the minimum observation count is increased to at least 2, 3, 5, and 10 slices. (B–E) Morphospaces independently refitted at each threshold, with identical plotting conventions but threshold-specific preprocessing, loadings, and scores. Representative VASEs identify the developmental interpretation of each space. (F) Leading feature loadings or feature-family contributions for the first principal components across thresholds. (G) Sign- and permutation-aware alignment of corresponding axes or leading subspaces, with [CODEX: insert metric and uncertainty]. (H) Representative histories illustrating which developmental forms persist, change, or disappear as minimally observed fires are removed. Sample sizes, explained variance, and quantitative alignment must be inserted from validated repository outputs; the figure should not imply robustness if the refitted spaces diverge.

[CODEX: Figure S2]

Insert the validated repository-generated figure here.

Figure S2: **Developmental organization after removal of absolute event attributes.** (A) Feature families included in the full multivariate and shape-only representations. (B) Full morphospace containing normalized developmental features and absolute event attributes. (C) Independently fitted shape-only morphospace excluding final area, recorded duration, observation count, absolute growth, slenderness, and [CODEX: insert other audited exclusions]. (D) Leading loadings and feature-family contributions in both spaces. (E) Quantitative correspondence between aligned scores, loadings, or leading subspaces. (F) Final area, duration, and observation count projected as external attributes onto the shape-only coordinates. (G) Representative VASE histories spanning the shape-only axes. The figure tests what developmental structure remains when endpoint information no longer defines the coordinate system.

[CODEX: Figure S3]

Insert the validated repository-generated figure here.

Figure S3: **Diagnostics supporting event-level environmental analyses.** (A) Complete Spearman correlation matrix relating weather representations to absolute and developmental responses, with sample size and [CODEX: insert uncertainty or significance convention]. (B) Response-specific held-out performance for every predictor group. (C) Performance across random-fire, year-block, region-block, and region–year validation. (D) Common-cohort comparison of nested predictor groups, including maximum-VPD ablations and duration or observation-count sensitivity. (E) Projection of the principal weather variables onto the shape-only morphospace [CODEX: include if generated]. These panels provide the detailed support for the simplified distributional weather result in the main text.

[CODEX: Figure S4]

Insert the validated repository-generated figure here.

Figure S4: **Empirical support and uncertainty for state-dependent weather associations.** (A) Number of transitions and distribution of calendar intervals represented by the shifted subsequent-growth response. (B) Joint density or binned sample size across VPD and current growth, identifying unsupported portions of the displayed domain. (C) Fitted VPD association at low, intermediate, and high current growth with [CODEX: insert uncertainty intervals]. (D) Incremental held-out performance of weather and weather–state interactions beyond state-only and persistence baselines. (E) Sensitivity across validation blocks or fire subsets [CODEX: insert final stratification]. The figure distinguishes an empirically supported state interaction from extrapolation and from the autoregressive information carried by current growth.

Supplementary Tables

Table S1: **Data products and analytical roles.**

Information source	Contents used	Analytical role	Scope and limitation
FIRED event information	Identifier, ignition and final dates, recorded duration, final area, final geometry	Defines events and supplies absolute attributes	Event delineation and duration inherit the observing system and FIRED rules
FIRED observed slices	Observation date, event-day field, newly and cumulatively mapped area	Provides the ordered area sequence encoded by Fire VASE	Adjacent observations are not assumed to be uninterrupted calendar days
Normalized VASE histories	Relative developmental time, ring area, cumulative area, normalized width	Standardizes whole histories for comparison	Records area allocation, not geographic shape or direction
Developmental features	Scalar traits and interpolated width and growth profiles	Quantifies timing, concentration, recurrence, and terminal behavior	Some features depend on observation depth or temporal spacing
Full morphospace	Normalized features plus absolute event attributes	Multivariate description used in the current main figures	Weather-independent but not endpoint-independent
Shape-only morphospace	Normalized developmental features only	Tests organization independent of endpoint and scale variables	Final definition and population [CODEX: insert after audit]
gridMET weather	Meteorological and fire-danger variables at observed dates	First external layer projected onto morphology	Fixed final-event centroid; active-edge conditions are not represented
Supplemental spatial exposure	Perimeter and burned-area-zone summaries	Candidate later exposure representation	Not the basis of present population inference

Table S2: **Complete developmental-feature provenance and morphospace inclusion audit.**

Feature	Definition	Units	Transform.	Within-fire norm.?	Obs.-count dependent?	Absolute scale?	Full PCA?	Shape-only PCA?	Interpretation and known limitation
Observation count	Number of retained slices	count	[CODEX: verify]	No	Yes	No	Yes	No	Measurement depth and possible persistence; no internal trajectory when equal to 1
Relative developmental time	Ordered position scaled from 0 to 1	unitless	linear scaling	Yes	Yes	No	Through derived features	Yes	Sequence position; not necessarily elapsed calendar time
Ring area	$g_{ij} = \max(g_{ij}^{\mathrm{raw}}, 0)$, where g_{ij}^{raw} is mapped increment	km^2	nonnegative clipping	No	No	Yes	Through derived features	No	Newly mapped area at an observed slice
Cumulative area	$A_{ij} = \sum_{k \le j} g_{ik}$	km^2	cumulative sum	No	Yes	Yes	Through width and final area	Through normalized width only	Accumulated mapped area
Normalized width	$\sqrt{A_{ij}/A_{iT_i}}$	unitless	square root	Yes	Yes	No	Yes	Yes	Radius-like cumulative trajectory
Normalized growth profile	[CODEX: insert exact normalization and interpolation]	unitless	interpolation to 11 points	Yes	Yes	No	Yes	Yes, subject to audit	Timing of incremental growth; interpolation depends on slice count
Width profile	Normalized width interpolated to 11 points	unitless	linear interpolation	Yes	Yes	No	Yes	Yes	Cumulative developmental form
Peak timing	Relative position of maximum observed growth	unitless	none	Yes	Yes	No	Yes	Yes	Early versus late maximum; unstable for very short histories
Front-loaded fraction	Area accumulated by relative time 0.5 divided by final observed area	proportion	none	Yes	Yes	No	Yes	Yes	Concentration in first half
Late-growth fraction	Area added after relative time 0.75 divided by final observed area	proportion	none	Yes	Yes	No	Yes	Yes	Concentration near end
Terminal taper	Final increment divided by maximum observed increment	ratio	none	Yes	Yes	No	Yes	Yes	Growth remaining at final observation

Feature	Definition	Units	Transform.	Within-fire norm.?	Obs.-count dependent?	Absolute scale?	Full PCA?	Shape-only PCA?	Interpretation and known limitation
Pulse count	Number of transitions into threshold-defined major-growth periods	count	[CODEX: verify model transformation]	No	Yes	No	Yes	[CODEX: audit]	Episodic growth; threshold and temporal-spacing sensitive
Reactivation count	max(pulse count $-1, 0$)	count	[CODEX: verify model transformation]	No	Yes	No	Yes	[CODEX: audit]	Recurrence after first major-growth period
Growth entropy	$-\sum p \log p / \log n$	unitless	probability normalization	Yes	Yes	No	Yes	Yes, after verification	Evenness; requires fractions that sum to one
Developmental velocity	Mean absolute first difference of normalized width	unitless per slice	none	Yes	Yes	No	Yes	[CODEX: audit]	Change per observed position, not necessarily per day
Developmental acceleration	Mean absolute second difference of normalized width	unitless per slice^2	none	Yes	Yes	No	Yes	[CODEX: audit]	Irregularity of width change; spacing sensitive
Final area	Final mapped event area	km^2	log	No	No	Yes	Yes	No	Conventional endpoint
Recorded duration	Source duration	days [CODEX: verify]	log	No	Yes	Yes	Yes	No	Conventional endpoint and observation-window attribute
Growth field labeled peak	[CODEX: verify formula and whether mean or maximum]	[CODEX: verify]	log	No	[CODEX: verify]	Yes	Yes	No	Absolute growth magnitude; name may require correction
Slenderness	[CODEX: insert exact formula]	[CODEX: verify]	log	No	Yes	Yes	Yes	No	Mixed duration–area attribute

Table S3: **Weather variables and event-level representations.**

Variable or representation	Source or calculation	Use in analysis
Maximum and minimum temperature	Daily gridMET; converted from Kelvin to degrees Celsius	Core summaries and extreme-slice fractions
Vapor pressure deficit	Daily gridMET mean VPD	Core predictor, tercile comparison, extremes, and state interaction
Wind speed	Daily gridMET	Core predictor and windy-slice fraction
Precipitation	Daily gridMET accumulation	Moisture predictor and wet-slice fraction
Relative and specific humidity	Daily gridMET	Moisture and humidity group
100-hour and 1000-hour fuel moisture	gridMET-derived dead fuel-moisture indices	Moisture group and dry-fuel-slice fraction
Energy release component and burning index	gridMET-derived fire-danger indices	Fire-danger group and high-ERC fraction
Reference and potential evapotranspiration	gridMET-derived variables	Fire-danger and energy group
Solar radiation	Daily downward surface shortwave radiation	Fire-danger and energy group
Event mean, minimum, and maximum	Summary across retained slices within fire	Event-level representation
Early, middle, and late means	Means within thirds of relative developmental time	Time-resolved representation
Region–month anomaly	Slice value minus median among fires in same region and month	Within-fire-population contrast
Extreme-slice fraction	Fraction exceeding percentile or precipitation threshold	Frequency of episodic exposure

Table S4: **Model comparisons, validation schemes, and diagnostic purpose.**

Component	Definition	Question addressed
Core weather	Event-mean maximum and minimum temperature, VPD, wind, and available maximum-VPD summaries	Transferable information in a compact atmospheric representation
Moisture and humidity	Precipitation, humidity, and dead fuel-moisture summaries	Whether moisture summaries explain different responses
Fire danger and energy	ERC, burning index, evapotranspiration, and solar radiation	Whether fire-danger and energy variables add information
Time-resolved weather	Early, middle, late, and extreme-slice summaries	Whether developmental timing improves prediction
Random-fire folds	Deterministic assignment across folds	Interpolation diagnostic
Year blocks	Broad time periods held out	Transfer across time
Region blocks	Broad regions held out	Transfer across space
Region–year groups	Hashed region–year combinations held out	Implemented spatiotemporal transfer test
Weather-only state model	Weather at current observed slice	Weather association with subsequent retained growth
State-only model	Developmental position, growth, cumulative area, and growth change	Autoregressive baseline
Additive model	Weather and state predictors	Incremental weather information after state is known
Interaction model	Core weather multiplied by selected state variables	Whether weather associations differ with state
Mismatch diagnostic	Standardized weather and morphology distances	Whether similarity in one representation implies similarity in the other

Table S5: **Explained variance across the full, observation-depth, and shape-only morphospaces.**

Morphospace	N fires	N features	PC1 (%)	PC2 (%)	PC3 (%)	PC4 (%)	PC5 (%)	Cumulative PC1–PC5 (%)
Full multivariate population	[CODEX: N]	[CODEX: N]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]
At least 2 slices	[CODEX: N2]	[CODEX: N]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]
At least 3 slices	[CODEX: N3]	[CODEX: N]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]
At least 5 slices	[CODEX: N5]	[CODEX: N]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]
At least 10 slices	[CODEX: N10]	[CODEX: N]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]
Shape only, [CODEX: population]	[CODEX: N]	[CODEX: N]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]	[CODEX: value]

Table S6: **Leading feature loadings and developmental interpretation of the primary morphospaces.**

Morphospace	Axis	Leading positive loadings	Leading negative loadings	Feature-family contribution	Developmental interpretation
Full multivariate	PC1	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]
Full multivariate	PC2	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]
Full multivariate	PC3	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]
Full multivariate	PC4	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]
Full multivariate	PC5	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]
Shape only	PC1	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]
Shape only	PC2	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]
Shape only	PC3	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]
Shape only	PC4	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]
Shape only	PC5	[CODEX: features and loadings]	[CODEX: features and loadings]	[CODEX: summary]	[CODEX: interpretation]

Table S7: **Summary of robustness questions, tests, and manuscript consequences.**

Question	Test	Metric or evidence	Result	Interpretation
Do gradients persist without single-slice fires?	Refit PCA for at least 2 slices	Loadings, variance, alignment, representative histories	[CODEX: result]	[CODEX: interpretation]
Do gradients persist with increasing observation depth?	Refit at 3, 5, and 10 slices	Cross-threshold alignment and feature-family stability	[CODEX: result]	[CODEX: interpretation]
Does observation count dominate a major axis?	Loading and projection audit	Loading magnitude, correlations, external projection	[CODEX: result]	[CODEX: interpretation]
Do gradients persist without endpoints?	Independently fit shape-only PCA	Variance, loadings, aligned subspaces, representative VASEs	[CODEX: result]	[CODEX: interpretation]
Do recognizable forms persist?	Compare representative histories across spaces	Glyph interpretation and quantitative neighborhood correspondence	[CODEX: result]	[CODEX: interpretation]
Do weather gradients persist in shape-only space?	Reproject weather and repeat principal summaries	Overlay correspondence and adjusted associations	[CODEX: result]	[CODEX: interpretation]
Does mismatch persist?	Repeat matching across robust spaces	Pair counts, distances, null comparison	[CODEX: result]	[CODEX: interpretation]
Is the VPD–state interaction supported?	Uncertainty and joint-support diagnostics	Intervals, sample density, incremental performance	[CODEX: result]	[CODEX: interpretation]

Supplementary References

References

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