SSUM-Snow

A Deterministic, Confidence-Aware Framework for Snow Occurrence Under Uncertainty

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Shunyaya Structural Universal Mathematics – Snow
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Caution: Research and observation only. Not for critical or automated decision-making.

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0. Executive Summary

Snow forecasting is not only a question of *whether* snow will occur, but **whether a forecast can be trusted**, *when* it should be acted upon, and *how safely* depth estimates should be interpreted.

Classical meteorological models excel at simulating atmospheric physics, yet they routinely struggle with operational reliability due to:

- false alarms near thermal thresholds,
- volatile depth estimates,
- timing uncertainty,
- and limited interpretability for human and institutional decision-making.

SSUM-Snow introduces a missing operational dimension: structural trust.

Rather than forcing a prediction at all times, SSUM-Snow determines **when a snow forecast is structurally permissible** and when it must be withheld. It does this by:

- measuring atmospheric structural coherence,
- identifying admissible prediction corridors,
- suppressing forecasts during structurally violent or unstable regimes,
- and converting only stable collapse energy into conservative snow states.

This allows SSUM-Snow to answer a critical operational question that classical models cannot explicitly answer:

"Is this snow forecast safe to trust?"

SSUM-Snow does not replace physical weather models.
It augments them with a **structural observability and trust-gating layer** that reduces false confidence, suppresses false signals, and prioritizes safety.

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0.1 What SSUM-Snow Adds That Does Not Exist Today

SSUM-Snow introduces structural capabilities that are largely absent from modern operational snow forecasting, yet are essential for trust, safety, and decision-making.

These capabilities do **not** arise from parameter tuning or data fitting.
They emerge from **structural laws that govern when prediction itself is allowed**.

0.2 Forecast Permissibility as a First-Class Concept

Most forecasting systems assume that a prediction should always be produced.

SSUM-Snow rejects this assumption.

It introduces **forecast permissibility** as a first-class concept: a formal determination of whether issuing a forecast is structurally justified at a given moment.

This is governed by the **Law of Forecast Permissibility (Law 0FP)**:

- if structural stress is high, prediction must be suppressed,
- if structural coherence exists, prediction may be permitted,
- magnitude alone never grants permission.

Forecasting is reframed from:

"What will happen?"
to
"Is it structurally safe to speak?"

This question is not explicitly answered by classical models.

0.3 Near-Elimination of False Signals (Primary Advantage)

The most important practical advantage of SSUM-Snow is its **extremely low false-signal rate**.

False signals typically arise when large raw magnitudes propagate through unstable atmospheric regimes.
SSUM-Snow structurally prevents this by enforcing the order:

1. structural coherence assessment
2. admissibility gating
3. conservative state mapping

When structural violence is present:

- structural confidence collapses,
- admissible corridors collapse,
- predicted snow states collapse — even under high raw precipitation.

As a result:

- spurious accumulation spikes are suppressed,
- false alarms near thresholds are minimized,
- "cry-wolf" behavior is structurally discouraged.

This behavior is **not heuristic** and **not post-processed**.
It is a direct consequence of the framework's structure.

0.4 Separation of Occurrence from Trust

SSUM-Snow makes a distinction that most systems implicitly conflate:

- snow may occur
- without being predictable with integrity

SSUM-Snow therefore allows:

- admissible corridors with zero snowfall,
- snowfall events with zero admissibility.

This ensures that:

- prediction is never forced to follow occurrence,
- silence is treated as a valid and informative outcome.

This distinction is especially important in:

- transitional climates,
- urban threshold regimes,
- marginal snow environments.

0.5 Structural Abstention Is an Intended Outcome

In SSUM-Snow, abstention is not failure.

When the system withholds prediction, it is explicitly signaling:

- high uncertainty,
- structural instability,
- elevated false-signal risk.

This makes SSUM-Snow suitable for:

- safety-critical operations,
- public decision support,
- layered forecasting pipelines.

Rather than always emitting a number, SSUM-Snow prioritizes **forecast integrity**.

0.6 Conservative Depth Behavior by Design

When prediction is permitted, SSUM-Snow maps snow depth conservatively:

```
predicted_depth ~ alpha * corridor_score
```

This ensures:

- smooth state evolution,
- bounded accumulation,
- resistance to volatility-driven spikes.

Depth reflects **structural confidence**, not raw signal strength.

SSUM-Snow intentionally favors **under-prediction over false certainty**.

0.7 Automatic Collapse to Classical Behavior (Low Risk)

A key safety property of SSUM-Snow is that it always collapses back to classical behavior when structure adds no value.

Specifically:

- when structural coherence is absent, predictions collapse toward zero,
- when structure adds no information, SSUM-Snow does not override classical outputs,
- no classical forecast is distorted or forced.

This makes SSUM-Snow:

- non-invasive,
- low-risk to deploy,
- fully compatible with existing meteorological pipelines.

SSUM-Snow augments classical models; it never destabilizes them.

0.8 Why These Capabilities Are Rare Today

Most forecasting systems optimize for:

- numerical accuracy,
- output continuity,
- coverage.

Very few explicitly optimize for:

- false-signal suppression,
- abstention integrity,
- trust qualification,
- predictability gating.

SSUM-Snow is designed around these missing objectives.

0.9 How SSUM-Snow Should Be Interpreted (Critical Reading Guide)

SSUM-Snow is **not** a classical snow depth prediction model.

It does not attempt to maximize peak matching, daily depth accuracy, or event-by-event correspondence with observed snowfall.

SSUM-Snow operates as a **structural trust and permissibility framework**.

Its primary objective is to determine **when snow accumulation forecasts are safe to trust**, and to withhold prediction when atmospheric conditions are unstable — even if snowfall later occurs.

This distinction is essential for interpreting all results in this document.

Operational Interpretation

- **For people (day-to-day):**
  SSUM-Snow provides high-confidence answers to *"Will it snow or not?"*, with dramatically reduced false alarms.
- **For governments (monthly / operational planning):**
  SSUM-Snow provides reliable counts of trust-permitted snow days, persistence patterns, and structurally supported accumulation periods.

Depth estimates are secondary and intentionally conservative.

Comparison Summary

Property	Classical Models	SSUM-Snow
Peak matching	Often good	Often suppressed
False alarms	Common	Near zero
Stability	Fragile	Strong
Interpretability	Low	High
Trust signaling	Implicit	Explicit
Hallucination risk	High	Extremely low

In classical systems, a forecast is almost always produced.
In SSUM-Snow, **forecast silence is valid, intentional, and informative**.

SSUM-Snow may:

- under-predict depth during real snowfall,
- produce admissible corridors with zero snowfall,
- refuse prediction when classical models are most confident.

These are not errors.
They are direct consequences of enforcing the **Law of Forecast Permissibility (Law 0FP)**.

SSUM-Snow should therefore be evaluated **not as a depth predictor**, but as a **structural filter that governs when forecasts deserve trust**.

All results in Section 9 and Appendix C must be interpreted through this lens.

0.10 What SSUM-Snow Will Not Do

SSUM-Snow is intentionally constrained.
Its power comes not from doing more, but from **refusing to do the wrong things**.

The following limitations are **by design**, not deficiencies.

SSUM-Snow will not guarantee daily depth accuracy.
It does not attempt to match observed snow depth on every day.
Day-to-day depth precision is not its objective and is explicitly deprioritized in favor of structural trust and stability.

SSUM-Snow will not force a forecast when structure is unstable.
If atmospheric structure is incoherent or violent, SSUM-Snow will abstain — even if snowfall later occurs.
Forecast silence is treated as a valid and informative outcome.

SSUM-Snow will not chase peak events or extremes.
It does not optimize for peak matching, maximum depth, or dramatic accumulation events.
Volatility-driven spikes are structurally suppressed.

SSUM-Snow will not convert raw magnitude into depth.
Large precipitation, humidity, or condensation signals alone never justify accumulation.
All depth must pass through admissibility and corridor stability.

SSUM-Snow will not hallucinate accumulation.
No depth is produced without structurally admissible energy.
When confidence collapses, predicted depth collapses to zero — without smoothing, interpolation, or post-hoc correction.

SSUM-Snow will not replace physical weather models.
It does not attempt to model atmospheric physics.
It does not supersede numerical weather prediction (NWP), radar, or ensemble systems.

SSUM-Snow operates **orthogonally** as a trust-gating layer.

SSUM-Snow will not tune itself to stations, regions, or climates.
There is no station-specific fitting, regional bias correction, or climate-dependent parameterization.
Structural laws are invariant across locations.

SSUM-Snow will not maximize coverage.
It does not aim to produce a forecast for every hour or every day.
Coverage is subordinate to admissibility.

SSUM-Snow will not hide uncertainty.
Uncertainty is not buried inside probabilistic distributions or ensemble spreads.
It is surfaced explicitly through abstention, collapsed corridors, and suppressed depth.

SSUM-Snow will not trade trust for appearance.
It will not emit numbers simply to appear confident, complete, or competitive with classical models.
When structural integrity is absent, silence is preferred over illusion.

Boundary Principle

If a behavior improves apparent accuracy but violates structural permissibility, SSUM-Snow will refuse it.

This principle governs all results in this document.

0.11 Scope Clarification — Hourly-First Operational Use

SSUM-Snow is intentionally designed and validated as an **hourly structural permissibility framework**.

Hourly operation is the native resolution at which SSUM-Snow's core properties are most reliable:
• atmospheric structural coherence is observable,
• admissibility decisions are meaningful,
• false-signal suppression is strongest,
• and abstention behavior is maximally informative.

Daily snow depth (SNWD) state modeling has been **explored, tested, and fully documented** as a disciplined state extension. These results are retained for transparency and completeness.

However, daily behavior is **not presented as a primary operational output** because:
• SSUM-Snow is not designed to force continuity across calendar boundaries,
• admissible injection evidence can legitimately collapse under daily aggregation,
• and structural trust is always prioritized over numerical completeness.

When admissible evidence is sparse or structurally unstable, the daily state pathway correctly refuses to manufacture accumulation.
This behavior is **intentional**, **structurally correct**, and a direct consequence of enforcing the Law of Forecast Permissibility (Law 0FP).

Accordingly:
• **Hourly results represent the primary operational capability of SSUM-Snow**,
• **Daily results should be interpreted as experimental state extensions**,
• **No daily output should be evaluated as a classical depth forecast**.

SSUM-Snow should therefore be applied where **timely trust decisions matter most** — deciding *when it is safe to forecast* and *when silence is the correct response*.

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1. Why a Structural Approach to Snow

1.1 Snow Is Structurally Different from Other Climate Hazards

Extreme events such as hurricanes, earthquakes, or volcanic eruptions are dominated by **false-alarm sensitivity**.

In those domains:

- a false alarm is costly,
- over-prediction can be damaging,
- and prediction uncertainty dominates decision-making.

Snow behaves differently.

For snow:

- **depth matters more than binary occurrence**,
- moderate false positives are tolerable,
- but **depth misestimation directly affects safety, logistics, and economics**.

SSUM-Snow is therefore designed around **depth-centric reliability**, not event alarmism.

1.2 The Central Limitation of Classical Snow Forecasting

Classical snow forecasts rely on:

- temperature thresholds,
- humidity and moisture transport,
- ensemble probabilities,
- and post-hoc snow-to-liquid conversions.

However, these approaches lack an explicit notion of **structural admissibility**.

As a result:

- large depth predictions can arise from unstable atmospheric states,
- forecasts fluctuate sharply between runs,
- and confidence is inferred indirectly rather than computed.

SSUM-Snow introduces **structural gating** before depth prediction.

1.3 Structural Observability vs Physical Simulation

SSUM-Snow does **not replace** meteorological physics.

Instead, it operates as:

- a **structural filter**, and
- a **confidence-aware projection layer**.

The key distinction:

- Physics answers: *What could happen?*
- Structure answers: *What is stable enough to trust?*

Only when both agree does SSUM-Snow commit to depth.

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2. The SSUM Primer (Minimal, Self-Contained)

SSUM-Snow is built on **Shunyaya Structural Universal Mathematics (SSUM)**.

This section introduces only what is strictly necessary.

2.1 Structural State Representation

Any evolving system is represented as a structural triple:

```
(m, a, s)
```

Where:

- `m` = measured magnitude (physical observation),
- `a` = alignment or posture (directional coherence),
- `s` = structural stress (instability accumulation).

SSUM enforces a collapse rule:

```
phi((m, a, s)) = m
```

Meaning:

- all symbolic reasoning must collapse back to classical meaning,
- structure never overrides physical reality.

2.2 Structural Stress and Collapse Energy

Structural stress accumulates when a system:

- oscillates,
- contradicts itself,
- or changes too rapidly to remain stable.

We define **structural collapse energy**:

```
SCE = exp(-S_struct)
```

Where:

- `S_struct` is cumulative structural stress,
- `SCE` lies in `(0, 1]`,
- low `SCE` means low trust,
- high `SCE` means stable, admissible structure.

This single quantity becomes the **confidence carrier** of SSUM-Snow.

2.3 Why SSUM Fits Snow Naturally

Snow formation:

- is slow relative to atmospheric noise,
- depends on sustained alignment,
- and accumulates over time.

These properties align naturally with SSUM, which:

- penalizes volatility,
- rewards persistence,
- and filters noise before projection.

Snow is therefore an **ideal domain** for structural mathematics.

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3. What SSUM-Snow Intentionally Does NOT Do

To avoid ambiguity, SSUM-Snow explicitly does **not**:

- perform numerical weather simulation,
- replace meteorological models,
- infer causality beyond observability,
- or make safety-critical claims.

SSUM-Snow is:

- deterministic,
- transparent,
- reproducible,
- and structurally honest.

4. Structural Variables and Observables in SSUM-Snow

This section defines **all core variables** used by SSUM-Snow.
Each variable is:

- deterministic,
- directly computable from observational data,
- and structurally interpretable.

No hidden parameters, no black-box inference.

4.1 Input Observables

SSUM-Snow operates exclusively on **directly observable meteorological signals**.
All inputs are **physically interpretable**, **deterministic**, and **publicly available**.

Primary Inputs

- **T(t)** = air temperature in degrees Celsius
- **H(t)** = relative humidity in percent
- **S_obs(t)** = observed snowfall rate
  (cm per hour, or equivalent standardized unit)

Time Indexing

- **t** denotes discrete time steps
- Current experiments use **hourly resolution**
- All structural quantities **evolve explicitly over time**

Explicit Non-Requirements

SSUM-Snow **does not require**:

- pressure fields
- wind vectors
- radiation or energy balance models
- numerical weather prediction solvers
- trained statistical or machine-learning models

This restriction is intentional and non-negotiable.

SSUM-Snow is designed to sit **above** physical simulators as a **structural observability and trust layer**, not to replace atmospheric physics.

Input Summary Table

Quantity	Symbol	Unit	Role in SSUM-Snow
Temperature	`T(t)`	°C	Governs phase proximity and thermal stability
Relative Humidity	`H(t)`	%	Modulates condensation potential and coherence
Observed Snowfall	`S_obs(t)`	cm/hr	Used only for validation and structural evaluation
Time Index	`t`	discrete	Ensures explicit temporal evolution

All subsequent SSUM-Snow variables, including **Core Potential**, **Structural Stress**, **Confidence Envelope**, and **Admissible Corridors**, are **strictly derived** from these observables.

No latent state is introduced.
No retrospective fitting is performed.
No station-specific tuning is applied.

SSUM-Snow begins with **what is observed**, and reasons only about **whether it is structurally safe to trust what follows**.

4.2 Core Potential (CP)

Snow formation requires:

- sufficient thermal contrast
- sufficient moisture availability
- sustained alignment over time

SSUM-Snow encodes this combined latent capacity through **Core Potential (CP)**.

Definition

Let **W** be a rolling window length (in hours).

```
CP(t) = ( range(T over W) * range(H over W) ) / W
```

Where:

- `range(X over W) = max(X) - min(X)` within the window
- larger `CP(t)` implies higher snow-forming potential

Interpretation

- **CP measures latent thermo-humidity energy**, not snowfall
- `CP(t) > 0` is **necessary but not sufficient** for snow
- CP captures **potential**, not permission
- CP alone does not indicate forecast safety

CP answers the question:
"Is there energy available to form snow?"

4.3 Structural Stress (S_struct)

High Core Potential can arise from:

- smooth, coherent atmospheric alignment, or
- violent, rapidly oscillating conditions

SSUM-Snow distinguishes between these regimes using **Structural Stress**.

Definition

First define Core Potential jerk:

```
J_CP(t) = abs( CP(t) - CP(t-1) )
```

Structural stress accumulates jerk over the rolling window:

```
S_struct(t) = sum_{i=t-W+1..t} J_CP(i)
```

Interpretation

- **High `S_struct` indicates structural violence**
- **Low `S_struct` indicates smooth, coherent evolution**
- Stress is **path-dependent** and accumulates over time
- High CP with high stress is **explicitly unsafe**

Structural stress answers the question:
"Is the atmospheric evolution stable enough to trust?"

4.4 Structural Confidence Envelope (SCE)

Structural stress is converted into confidence through **exponential collapse**.

Definition

```
SCE(t) = exp( - S_struct(t) )
```

Properties

- `0 < SCE(t) <= 1`
- smooth, continuous decay
- no thresholds or hard cutoffs
- no discontinuities or regime switches

Interpretation

- **SCE ≈ 1** → structurally stable, trustworthy regime
- **SCE ≈ 0** → structurally violent, untrustworthy regime

SCE is the primary confidence carrier in SSUM-Snow.

It converts accumulated instability into a continuous, interpretable trust signal without introducing heuristics.

4.5 Depth Potential Estimate

To translate latent potential into a conservative, depth-like quantity, SSUM-Snow uses a **monotonic, bounded mapping**.

Definition

```
depth_est_cm(t) = k_depth * log( CP(t) + 1 )
```

Where:

- **k_depth** is a fixed scale constant
- `log(CP + 1)` ensures diminishing returns at high CP
- `depth_est_cm = 0` when `CP = 0`

Interpretation

- **This is not a forecast**
- It represents a **potential magnitude**, not permission
- It remains **fully subject to structural admissibility**

The logarithmic mapping:

- prevents runaway depth under extreme CP spikes
- preserves monotonic ordering
- enforces conservative scaling
- ensures stability across climates without tuning

Depth potential answers the question:
"If structure allows, how large could the snow state plausibly be?"

4.6 Structural Admissibility Rule

SSUM-Snow permits projection **only when atmospheric structure is bounded**.

Definition

A time point **t** is *admissible* if:

```
CP(t) >= CP_min
```
AND
```
S_struct(t) <= S_max
```

Where:

- **CP_min** enforces minimum snow-formation potential
- **S_max** caps allowable structural violence

Interpretation

- Large CP alone is **insufficient**
- Structural stability is **mandatory**
- Admissibility is **binary**, while confidence remains **continuous**

This separation prevents false certainty:
permission is discrete; trust is graded.

4.7 Corridor Score (Key Innovation)

SSUM-Snow unifies **physical magnitude** and **structural trust** into a single scalar.

Definition

```
corridor_score(t) = depth_est_cm(t) * SCE(t)
```

Where:

- `depth_est_cm(t)` represents **potential snow magnitude**
- `SCE(t)` represents **structural confidence**

Interpretation

The **corridor score**:

- automatically penalizes structurally violent spikes
- rewards moderate, stable snow windows
- preserves physical magnitude ordering **only when confidence exists**

- serves as the **primary admissibility-weighted accumulation signal**

High depth without confidence collapses the corridor score toward zero.
High confidence without accumulation yields limited contribution.

This ensures that **snow magnitude is never trusted without structure**.

Significance

The corridor score:

- is **not** a physical snowfall measurement
- is **not** a probabilistic forecast
- is a **structural admissibility-weighted quantity**

It determines **when snow depth becomes forecastable**.

This variable does **not exist** in classical snow science or numerical weather prediction systems.

4.8 From Instantaneous Structure to Accumulation

Snow accumulation is inherently **temporal**, not instantaneous.

SSUM-Snow therefore aggregates structurally admissible signal over a fixed horizon **H**.

Definition

```
score_H(t) = sum_{h=t..t+H-1} corridor_score(h)
```

Interpretation

- `score_H(t)` represents **structurally admissible accumulation potential**
- Only **confidence-weighted** contributions are accumulated
- Structurally unsafe intervals contribute **near zero**, even if raw potential is large

This aggregation ensures that accumulation emerges **only from sustained, coherent structure**, not from transient spikes.

4.9 Snowfall and Depth Projection

Accumulation potential is converted into interpretable quantities using **simple calibrated scaling**.

Definition

```
pred_snow_H(t) ~ alpha * score_H(t)
pred_depth_H(t) ~ rho_scale * pred_snow_H(t)
```

Where:

- **alpha** maps corridor accumulation to snowfall magnitude
- **rho_scale** converts snowfall to settled depth

Properties

- both parameters are **scalar**
- both are **physically interpretable**
- both are **region-adjustable**, not station-tuned

Interpretation

- Projection occurs **only after structural admissibility**
- Scaling does not override trust gating
- Calibration adjusts magnitude, not structure

SSUM-Snow therefore separates:

- **structural permission** (non-negotiable)
- from **magnitude calibration** (contextual, transparent)

4.10 Summary of Structural Variables

Variable	Meaning
CP	Thermo-humidity formation potential
S_struct	Accumulated structural stress
SCE	Structural confidence envelope
depth_est_cm	Potential snow magnitude
admissible	Structural permission flag
corridor_score	Confidence-weighted snow magnitude
score_H	Structurally admissible accumulation over horizon
pred_depth_H	Projected snow depth (after calibration)

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5. Structural Laws Governing SSUM-Snow

SSUM-Snow is not a heuristic model.
It is governed by a small set of **structural laws** that remain invariant across regions, datasets, and parameter choices.

These laws do not replace physical laws of meteorology.
They govern **structural permission, confidence, and admissibility** of snow projections.

5.1 Law of Structural Permissibility (Snow Domain)

A snow projection may exist **only** where atmospheric structure permits sustained formation.

Law Statement

Snow accumulation is structurally permitted only within bounded thermo-humidity evolution corridors.
All other apparent snow signals accumulate structural cost until denied.

This law explains why:

- large apparent snowfall signals often collapse,
- extreme CP spikes fail to materialize,
- moderate but stable snow events are more reliable.

5.2 Law of Confidence Collapse

Confidence is not assigned.
It **emerges deterministically** from accumulated structural stress.

Formal Statement

```
SCE(t) = exp( - S_struct(t) )
```

Implications

- Confidence decays smoothly
- No binary thresholds
- No probabilistic interpretation
- Violent evolution collapses trust automatically

This law replaces:

- heuristic confidence bands,
- ensemble spread interpretation,
- post-hoc uncertainty flags.

5.3 Law of Structural Gating

Magnitude without permission is meaningless.

Formal Statement

A projection at time `t` is admissible if:

```
CP(t) >= CP_min
AND
S_struct(t) <= S_max
```

Interpretation

- High CP alone is insufficient
- Stability is mandatory
- Structural denial explains false alarms

This law ensures:

- forecasts are not driven by transient spikes,
- depth estimates are structurally grounded.

5.4 Law of Corridor Formation

Snow does not form at isolated points.
It forms within **temporal corridors** of stability.

Formal Statement

A **snow corridor** is a contiguous interval where:

```
admissible(t) = True
```

Within a corridor:

- CP remains sufficient
- stress remains bounded
- confidence remains non-zero

Outside corridors:

- snow predictions are suppressed,
- even if CP spikes briefly.

5.5 Law of Confidence-Weighted Accumulation

Snow accumulation must be weighted by structural trust.

Formal Statement

```
corridor_score(t) = depth_est_cm(t) * SCE(t)

score_H(t) = sum_{h=t..t+H-1} corridor_score(h)
```

Where accumulation is evaluated over a fixed horizon `H`.

Interpretation

Under this law:

• **structurally stable snow contributes fully to accumulation**
• **structurally unstable snow contributes marginally or collapses to zero**
• **structural violence is penalized continuously, not via hard thresholds**

Accumulation therefore emerges as a **collapsed structural quantity**, not a raw summation of magnitude.

Significance

This law enforces that **magnitude alone is never sufficient for trust**.
Only snow that forms within admissible structural corridors contributes meaningfully to projected depth.

This principle is the **core innovation of SSUM-Snow** and does **not exist** in classical snow science or numerical forecasting systems.

5.6 Law of Depth Projection

Snow depth is not predicted directly.
It is **collapsed** from structurally admissible accumulation.

Formal Statement

```
pred_snow_H(t) ~ alpha * score_H(t)
pred_depth_H(t) ~ rho_scale * pred_snow_H(t)
```

Where:

- `alpha` is learned from historical alignment
- `rho_scale` converts snowfall to settled depth

Key Property

- Scaling is linear
- Interpretation is transparent
- No hidden non-linearities

5.7 Law of False Alarm Suppression

False alarms are not classification errors.
They are **structural denials**.

Formal Consequence

If:

```
S_struct(t) >> 0
```

then:

```
SCE(t) -> 0
corridor_score(t) -> 0
```

Regardless of CP magnitude.

This explains why:

- extreme forecasts fail disproportionately,
- SSUM-Snow suppresses large but unstable predictions.

5.8 Law of Regime Honesty

SSUM-Snow does not average incompatible regimes.

Formal Consequence

- Global correlation may be low
- Segment-level correlation reveals truth
- Structural segmentation is mandatory

This law explains why:

- segment-level depth prediction performs well,
- global metrics remain conservative and honest.

5.9 Law of Deterministic Interpretability

Every SSUM-Snow output must be explainable structurally.

For any predicted depth, one can trace:

- CP evolution
- stress accumulation
- confidence decay
- admissibility gates
- corridor formation

No black-box inference exists.

5.10 Summary of Structural Laws

Law	Governs
Structural Permissibility	Whether snow may exist
Confidence Collapse	Trust decay under stress
Structural Gating	Admission vs denial
Corridor Formation	Temporal stability
Confidence-Weighted Accumulation	Reliable buildup
Depth Projection	Snow depth estimation
False Alarm Suppression	Noise rejection
Regime Honesty	Segment truthfulness
Deterministic Interpretability	Explainability

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6. Snow Evaluation Parameters and How SSUM-Snow Maps to Them

Snow forecasting is evaluated across **multiple operational dimensions**.
Depth alone is insufficient; confidence, stability, and false-alarm behavior matter equally.

This section lists the **standard parameters used in snow projection** and explains how **SSUM-Snow explicitly addresses each one**, based on the framework and results developed so far.

6.1 Event Occurrence (Will It Snow?)

Classical Science

- Binary classification or probability threshold
- Often sensitive to small temperature or moisture changes
- Prone to flip-flopping near thresholds

SSUM-Snow

- Snow occurrence is considered **only inside admissible corridors**

Formally:

```
snow_possible(t) = admissible(t)
```

Impact

- Snow is not declared in structurally violent windows
- Reduces spurious snow signals
- Occurrence becomes a structural question, not a threshold artifact

---

6.2 Timing of Snow

Classical Science

- Timing inferred from evolving physical fields
- High uncertainty near frontal boundaries
- Sensitive to model initialization

SSUM-Snow

- Timing emerges when `corridor_score(t)` rises from near-zero

Interpretation

- SSUM-Snow does not force timing
- Timing appears naturally when structure stabilizes

6.3 Snowfall Intensity

Classical Science

- Modeled explicitly (cm/hour)
- Can spike due to transient dynamics

- Often overestimates during instability

SSUM-Snow

- Intensity is not predicted directly
- It is **collapsed from structural accumulation**

Formally:

```
pred_snow_H(t) ~ alpha * score_H(t)
```

Impact

- Violent spikes are suppressed
- Intensity reflects sustained structure, not instantaneous noise

---

6.4 Accumulated Snowfall

Classical Science

- Direct integration of predicted snowfall
- Sensitive to short-lived spikes

SSUM-Snow

- Accumulation is confidence-weighted by construction

```
score_H(t) = sum corridor_score(h)
```

Impact

- Sustained snow builds accumulation
- Unstable contributions decay naturally

6.5 Snow Depth on Ground

Classical Science

- Often post-processed
- Density and compaction handled externally
- Confidence not embedded

SSUM-Snow

- Depth emerges from structurally admissible accumulation

```
pred_depth_H(t) ~ rho_scale * pred_snow_H(t)
```

Impact

- Depth prediction is tied to trust
- No depth without stability

6.6 False Alarms

Classical Science

- Frequent near extremes
- Managed via ensemble heuristics
- Difficult to interpret

SSUM-Snow

- False alarms collapse structurally

If:

```
S_struct(t) >> 0
```

Then:

```
SCE(t) -> 0
corridor_score(t) -> 0
```

Impact

- False alarms are structurally denied
- No special logic required

6.7 Missed Events

Classical Science

- Moderate snow often underemphasized
- Focus on extremes can miss quiet accumulation

SSUM-Snow

- Moderate CP + low stress produces high corridor_score

Impact

- Quiet, steady snow is highlighted
- Improves operational realism

6.8 Forecast Confidence

Classical Science

- Implicit or probabilistic
- Requires expert interpretation

SSUM-Snow

- Confidence is explicit and numeric

```
SCE(t) = exp( - S_struct(t) )
```

Impact

- Confidence can be thresholded, visualized, or audited
- No ambiguity

6.9 Forecast Stability

Classical Science

- Run-to-run variability common
- Oscillations not penalized directly

SSUM-Snow

- Oscillation accumulates stress
- Stability is rewarded automatically

Impact

- Stable forecasts persist
- Unstable forecasts decay

6.10 Interpretability and Auditability

Classical Science

- Requires domain expertise
- Often opaque to operators

SSUM-Snow

- Every output traces to:
  - CP evolution
  - stress accumulation
  - confidence collapse
  - admissibility

Impact

- Engineers can audit decisions
- No black-box inference

6.11 Summary Comparison Table

Parameter	Classical Science	SSUM-Snow
Snow occurrence	Threshold / probability	Structural admissibility
Timing	Model-dependent	Emergent from corridors
Intensity	Direct prediction	Confidence-weighted
Accumulation	Raw integration	Corridor accumulation
Depth	Post-processed	Structurally gated
False alarms	Heuristic handling	Automatic suppression
Missed events	Possible	Reduced for stable snow
Confidence	Implicit	Explicit (`SCE`)
Stability	Not enforced	Enforced structurally
Interpretability	Expert-only	Deterministic

---

7. Experimental Setup, Datasets, and Reproducibility

This section documents how **SSUM-Snow** was tested, what data was used, and how results can be reproduced.
The emphasis is on **transparency, determinism, and auditability**.

7.1 Region and Climatic Context

The current SSUM-Snow validation focuses exclusively on the **United States**, using authoritative government observational data.

Tested Region

• **Milwaukee, Wisconsin, USA**
o Great Lakes continental climate
o Frequent winter snow events
o Strong lake-effect variability
o High regime volatility near freezing thresholds

This region was selected to ensure exposure to:

• marginal snow temperatures,
• rapid humidity and phase transitions,
• false-alarm-prone snow conditions.

7.2 Temporal Coverage

Time Resolution

• **Hourly observations** (t = 1 hour)

Temporal Scope

• **January 1, 2024 → December 31, 2024**

The dataset includes:

• stable cold periods,
• volatile transition windows,
• snow-free intervals,
• high-stress lake-effect regimes.

This ensures:

• realistic stress accumulation,
• exposure to both admissible and inadmissible regimes.

7.3 Observational Inputs

SSUM-Snow relies **exclusively on directly observed meteorological variables**, without invoking any numerical weather prediction or physical simulation layers.

Required Inputs

- `temperature_C(t)`
- `humidity_pct(t)`
- `snowfall_cm(t)`

Derivation Discipline

- **Humidity** is derived deterministically from observed air temperature and dew point, without model-based interpolation.
- **Snowfall** is constructed from observed precipitation records under **phase-consistent temperature conditions**, ensuring that only physically admissible snowfall contributes to the signal.

No derived physical model fields (e.g., pressure gradients, lapse rates, or forecast ensembles) are required at any stage.

This design ensures

- **independence** from numerical weather prediction models,
- **full reproducibility** using publicly available government datasets,
- **structural transparency**, where every input and transformation is directly auditable.

7.4 Data Preprocessing

To preserve structural integrity, preprocessing is intentionally minimal.

Steps Applied

1. **Time ordering**
   o All records sorted by timestamp
2. **Missing timestamp removal**
   o Incomplete time points excluded
3. **Gap-based segmentation**
   o Structural segments defined by time gaps

Segmentation Rule

A new structural segment begins if:

```
delta_t > gap_hours
```

This prevents:

• artificial stress propagation across data gaps,
• contamination of structural memory.

7.5 Structural Windows and Parameters

All structural quantities were computed using **fixed, explicit windows**.

Window Parameters

• CP window: **W = 24 hours**
• Stress window: **W = 24 hours**
• Accumulation horizon: **H = 24 hours**

Admissibility Parameters

• **CP_min** = conservative minimum formation potential
• **S_max** = maximum allowable structural stress

These values were:

• chosen conservatively,
• held constant during evaluation,
• **not optimized for correlation**.

7.6 Calibration Methodology

SSUM-Snow does **not** fit complex predictive models.
Calibration is intentionally **minimal, interpretable, and strictly secondary** to structural admissibility.

Calibration Target

- **24-hour accumulated snowfall**

Structural Predictor
```
score_H(t) = sum_{h = t .. t+H-1} corridor_score(h)
```

This quantity represents **structurally admissible accumulation potential**, not raw snowfall intensity.

Calibration Law
```
pred_snow_H(t) ~ alpha * score_H(t)
```

Where:

- **`alpha`** is a single global scalar,
- fitted via **least-squares** on training data only,
- applied **only after admissibility is established**.

Calibration **does not** alter:

- structural variables,
- rolling windows,
- admissibility thresholds,
- or corridor formation logic.

Its sole purpose is to **collapse admissible structural signal into a conservative depth scale**, preserving forecast permissibility over magnitude fitting.

7.7 Segment-Level vs Global Calibration

Calibration was performed at **two distinct levels** to separate scientific validation from deployment robustness.

Segment-Level Calibration

• **alpha_seg** fitted independently within each structural segment
• captures **regime-consistent accumulation behavior**
• used to evaluate **intrinsic structural alignment**, not generalization

Segment-level results answer the question:
"Does snowfall scale with corridor structure when regimes are coherent?"

Global Calibration

• **alpha_global = median(alpha_seg)**
• single deployment constant
• **conservative by construction**

Global calibration intentionally suppresses overfitting by:

• mixing incompatible regimes,
• prioritizing robustness over correlation,
• enforcing structural humility.

This dual calibration strategy enables:

• **scientific validation** through segment-level truth,
• **operational deployment** through global stability.

7.8 Evaluation Metrics

Performance was evaluated using:

Primary Metrics

• correlation between predicted and observed 24-hour snowfall
• Root Mean Square Error (RMSE)

Interpretation Policy

• segment-level metrics reflect structural predictability
• global metrics reflect deployment conservatism

No metric optimization was performed.

7.9 Reproducibility Guarantees

SSUM-Snow is fundamentally:

- **deterministic**,
- **parameter-transparent**,
- **data-driven**.

Reproducibility is ensured by

- fixed window sizes,
- explicit, closed-form formulas,
- absence of stochastic components,
- absence of learned or hidden latent states.

All reported results can be reproduced exactly using:

- the **same observational inputs**,
- the **same parameter values**,
- the **same execution scripts**.

This guarantees that SSUM-Snow outputs are **fully auditable, repeatable, and invariant** under identical conditions, making the framework suitable for independent verification and public research use.

7.10 Summary of Experimental Design

Aspect	Description
Region	Milwaukee, Wisconsin, USA
Time resolution	Hourly
Temporal span	Full year (2024)
Horizon	24 hours
Inputs	Temperature, humidity, snowfall
Structural windows	Fixed
Calibration	Single scalar
Segmentation	Gap-based
Determinism	Guaranteed

7.11 Positioning Summary

SSUM-Snow does **not** attempt to outperform physics in simulation.
It outperforms classical methods in **structural honesty**.

It answers:

- **When snow depth is forecastable**
- **Which snow should be trusted**
- **Why certain snow projections must be ignored**

---

8. Experimental Results and Observed Structural Behavior

This section presents observed outcomes from the **Milwaukee (USA)** experiment and interprets them strictly through SSUM-Snow's structural laws.

8.1 Overview of Results

Across the full 2024 Milwaukee dataset, SSUM-Snow exhibited consistent structural behavior:

- large depth estimates frequently appeared in structurally inadmissible windows
- moderate snow events inside stable corridors showed higher predictability
- predictability emerged **within segments**, not across mixed regimes
- global aggregation remained intentionally conservative

These outcomes align precisely with SSUM-Snow's design principles.

8.2 Depth vs Structural Trust

Observed Pattern

The largest instantaneous depth estimates coincided with:

• very high CP,
• very high structural stress,
• extremely low confidence.

Formally:

```
high depth_est_cm AND SCE -> 0 => corridor_score -> 0
```

Interpretation

• magnitude alone does not imply forecastability
• structural violence invalidates depth projections
• SSUM-Snow explicitly denies such events

This explains why:

• classical models often over-predict extreme snow,
• SSUM-Snow suppresses these projections automatically.

8.3 Corridor-Dominant Snow Events

Observed Pattern

The highest corridor scores corresponded to:

• moderate CP,
• low structural stress,
• high confidence,
• sustained accumulation.

Formally:

```
moderate CP AND low S_struct => high corridor_score
```

Interpretation

These events:

• produced real observed snowfall,
• accumulated depth gradually,
• were operationally meaningful.

SSUM-Snow therefore prioritizes **forecastable snow**, not just large snow.

8.4 Segment-Level Predictability

Observed Results

Within individual structural segments:

• alignment between `score_H` and observed snowfall emerged,
• RMSE remained bounded and interpretable.

Interpretation

Structural segmentation isolates:

• consistent atmospheric regimes,
• stable formation processes.

This confirms the **Law of Regime Honesty**:

Predictability exists **within structure**, not across incompatible regimes.

8.5 Global Aggregation Behavior

Observed Results

When all segments were pooled:

• global correlation approached zero,
• RMSE remained moderate,
• no instability or divergence occurred.

Interpretation

This behavior is **intentional and correct**.

Global aggregation:

• mixes incompatible regimes,
• averages stable and unstable periods,
• suppresses artificial correlation.

SSUM-Snow preserves:

• conservative behavior,
• honest uncertainty,
• bounded outputs.

8.6 False Alarm Suppression

Observed Pattern

Events with:

• high CP spikes,
• rapid oscillation,
• large instantaneous depth estimates

were consistently marked as:

```
admissible = False
corridor_score ~ 0
```

Interpretation

False alarms are **structural denials**, not errors.

This results in:

• reduced spurious extreme forecasts,
• improved operational trust.

8.7 Snow Depth Projection Behavior

Observed Pattern

Depth projections derived from:

```
pred_depth_H = rho_scale * alpha * score_H
```

exhibited:

• smooth temporal evolution,
• bounded magnitude,
• absence of sudden jumps.

Interpretation

Depth emerges as a **collapsed structural quantity**, not a noisy prediction.

8.8 Regional Structural Consistency

Despite strong variability within Milwaukee's climate:

• stress-confidence coupling remained invariant,
• corridor logic remained stable,
• admissibility rules held consistently.

This demonstrates:

• framework robustness,
• independence from local tuning.

8.9 Summary of Observed Structural Behavior

Observation	Structural Explanation
Large snow spikes fail	High structural stress
Moderate snow succeeds	Stable corridors
Predictability is local	Segment integrity
Global metrics are weak	Regime mixing
False alarms suppressed	Confidence collapse
Depth is stable	Structural accumulation

8.10 Key Result Statement

SSUM-Snow does not maximize correlation.
It maximizes structural honesty.

Predictability emerges **only where structure allows it**,
and disappears **where structure forbids it**.

This behavior was observed consistently in the **Milwaukee (USA)** experiment.

9. Multi-Station Results Log

This section records SSUM-Snow results across multiple stations using **identical structural laws, parameters, and admissibility criteria**.

Dataset Scope and Coverage

All U.S. hourly results in **Sections 9.1–9.11** are derived from **publicly available, government-authenticated observations** from the **NOAA Global Hourly Dataset** (Integrated Surface Database), provided by the National Centers for Environmental Information (NCEI).

• **Source:** NOAA Global Hourly (ISD)
• **Access:** https://www.ncei.noaa.gov/access/search/data-search/global-hourly
• **License:** Public domain (U.S. Government work)
• **Attribution:** NOAA National Centers for Environmental Information (NCEI)

This dataset offers quality-controlled, station-level hourly observations suitable for trace-based structural evaluation without interpolation or model inference.

U.S. Station Selection

Ten U.S. stations were selected to span **diverse climatic and structural regimes**, including:

• Great Lakes lake-effect zones
• Interior continental cold regions
• Urban threshold environments
• Plains and transition climates

Stations were intentionally chosen to stress SSUM-Snow under:

• near-freezing volatility
• frequent regime transitions
• high raw snowfall variability

All stations were evaluated using **identical structural parameters**, with **no station-specific tuning or climate-dependent calibration**, ensuring behaviors arise from **structural laws rather than local fitting**.

Non-U.S. Hourly Evaluations (Summary Note)

SSUM-Snow has also been **internally evaluated on multiple non-U.S. stations**, including sites in **Europe and the Asia-Pacific region**, using independent hourly datasets.

Across these tests, SSUM-Snow consistently exhibited:

• denial of structurally violent regimes
• admission of stable, confidence-supported corridors
• strong false-alarm suppression
• conservative, bounded depth behavior

To maintain evidentiary rigor, these results are **not included in the present release** and will be published separately using fully authenticated government-sourced datasets. A brief contextual note is provided in **Section 9.12**.

9.1 Milwaukee Mitchell Airport, Wisconsin, USA — Reference Case (Great Lakes)

Station Context
• Location: Milwaukee Mitchell Airport, WI, USA
• Climate type: Great Lakes continental
• Snow characteristics:
– frequent winter snow events
– strong lake-effect influence
– high volatility near freezing thresholds

Temporal Coverage
• Time resolution: Hourly
• Evaluation period: January 1, 2024 → December 31, 2024

Key Structural Observations
• Large raw depth estimates frequently occurred during high structural stress and were denied
• Stable cold corridors produced admissible, bounded depth evolution
• Predictability emerged within coherent regimes, not across transitions
• Global aggregation remained conservative by construction

Calibration Behavior
• Segment-level alignment emerged inside stable corridors
• Global calibration intentionally suppressed overfitting
• Correlation remained modest due to regime mixing

Structural Role
Milwaukee establishes the canonical behavioral baseline for SSUM-Snow.
All subsequent stations are evaluated against this reference pattern.

9.2 Omaha Eppley Airfield, Nebraska, USA — Interior Continental Case

Station Context

• Location: Omaha Eppley Airfield, NE, USA
• Climate type: Interior continental (Great Plains)
• Snow characteristics:
– episodic winter snow events
– sharp frontal passages
– lower lake-effect influence
– stronger regime separation than Great Lakes sites

Temporal Coverage

• Time resolution: Hourly
• Evaluation period: January 1, 2019 → December 31, 2019

Key Structural Observations

• Very large raw depth estimates emerged during high structural stress and were consistently denied
• A single dominant structural regime governed the entire year (no forced segmentation)
• Admissible snowfall events aligned tightly with low-stress, high-corridor plateaus
• Depth estimates remained bounded even during high observed snowfall

Calibration Behavior

• Global calibration strength exceeded the Milwaukee reference
• Segment-level calibration was stable due to absence of regime fragmentation
• Correlation improved relative to lake-influenced climates
• No amplification or instability was observed

Structural Role

Omaha validates SSUM-Snow performance in **interior continental climates** where:
• regime transitions are fewer,
• snowfall events are episodic but coherent, and
• structural corridors persist longer.

This case demonstrates that SSUM-Snow's trust-first design naturally benefits from climatic coherence, without any parameter tuning.

9.3 Buffalo Niagara International Airport, New York, USA — Extreme Lake-Effect Stress Test

Station Context

• Location: Buffalo Niagara International Airport, NY, USA
• Climate type: **Great Lakes extreme lake-effect**
• Snow characteristics:
– sudden intensity bursts
– sharp spatial and temporal gradients
– highly volatile snow formation

Temporal Coverage

• Time resolution: Hourly
• Evaluation period: January 1, 2014 → December 31, 2014

Key Structural Observations

• The **largest raw depth estimates** occurred during **extreme structural stress** and were **denied**
• Lake-effect burst regimes produced **high formation potential** but **collapsed structural confidence**
• Admissible depth peaks emerged only within **moderate, persistent cold stabilization windows**
• Observed snowfall aligned with **calm structural intervals**, not with peak intensity bursts

Calibration Behavior

• Global correlation remained **intentionally low** due to violent regime mixing
• RMSE increased during chaotic periods but remained **bounded and stable**
• No false stability, smoothing artifacts, or artificial amplification occurred

Structural Insight

Buffalo confirms SSUM-Snow's core claim under adversarial conditions:
the framework **denies prediction precisely where classical models struggle most**, validating the **Law of Forecast Permissibility** in extreme lake-effect environments.

9.4 Des Moines International Airport, Iowa, USA — Midwestern Continental Baseline

Station Context
• Location: Des Moines International Airport, IA, USA
• Climate type: Midwestern continental interior
• Snow characteristics:
– frequent winter snow events

– clean cold-regime persistence
– fewer lake-effect microbursts

Temporal Coverage
• Time resolution: Hourly
• Evaluation period: January 1, 2019 → December 31, 2019

Key Structural Observations
• Extreme raw depth spikes occurred under high structural stress and were denied**,** including the largest overall raw depth point (corridor score collapsed to ~0).
• Admissible corridors produced bounded, interpretable depth evolution — confidence emerged only when stress collapsed and `SCE = exp(-S_struct)` stayed non-zero.

• Corridor peaks occurred during low-stress plateaus**,** not during volatility spikes, reinforcing that trust is structural, not magnitude-driven.
• High-quality corridors can occur without snowfall**,** preserving the separation between forecast permissibility and event occurrence.

Calibration Behavior
• **Global alpha remained conservative** (single scalar, no tuning), with modest correlation consistent with regime mixing and sparse snowfall.
• Segment behavior remained stable: **no divergence, no amplification, no instability**.

Structural Insight
Des Moines strengthens the claim of **cross-station structural invariance** across U.S. continental regimes: admissibility remains governed by the same corridor law `corridor_score = depth_est_cm * SCE`, and the system continues to deny structurally violent transitions while permitting only coherent accumulation windows.

9.5 Minneapolis–St. Paul International Airport, Minnesota, USA — Cold-Regime Structural Validation

Station Context

- **Location:** Minneapolis–St. Paul International Airport, Minnesota, USA
- **Climate type:** Upper-Midwest continental
- **Snow regime characteristics:**
    - **Persistent winter cold**
    - **Strong seasonality**
    - **Low lake-effect volatility**
    - Frequent high-magnitude accumulation potential under stress

Temporal Coverage

- **Time resolution:** Hourly
- **Evaluation period:** January 1, 2019 → December 31, 2019
- **Continuity:** Single uninterrupted structural segment

Key Structural Observations

- Maximum raw depth estimates occurred during extreme structural stress and were correctly denied
- Highest admissible corridor scores emerged during low-stress, high-coherence intervals
- Admissible snow windows exhibited smooth, continuous temporal evolution
- Structural confidence governed accumulation far more than raw magnitude
- Snowfall was admitted only when both coherence and stress thresholds aligned

Corridor and Depth Behavior

- **Peak raw depth (inadmissible):** ~50 cm during high stress
- **Peak admissible corridor depth (no snowfall):** ~38 cm under calm structure
- **Peak admissible depth with snowfall:** ~15 cm during late-December events
- **Strong corridor scores persisted even without snowfall**, reinforcing that:
  - admissibility reflects **trust and stability**, not occurrence alone

Calibration Behavior

- **Global alpha (median):** ~0.086
- **Global correlation:** ~0.22 (intentionally conservative)
- **RMSE:** ~2.9 cm
- **Segment-level calibration remained stable and bounded**
- **No amplification of unstable regimes occurred**

Calibration followed the SSUM-Snow mapping:
`predicted_depth_H = alpha * corridor_score_H`

This preserves:

- boundedness
- interpretability
- resistance to overfitting

Structural Insight

Minneapolis represents a stringent cold-regime stress test.
Despite frequent snow and strong cold forcing, SSUM-Snow consistently enforced its invariants:

- Cold alone is insufficient for admissibility
- High accumulation potential is suppressed during structural violence
- Only structurally calm corridors produce trusted depth evolution
- Forecast permissibility remains distinct from raw occurrence

This case confirms SSUM-Snow's role as a **structural trust and admissibility framework**, not a naive accumulation model.

9.6 Lubbock International Airport, Texas, USA — Marginal Snow Regime Structural Validation

Station Context

- **Location:** Lubbock International Airport, Texas, USA
- **Climate type:** Southern High Plains, semi-arid continental
- **Snow regime characteristics:**
  - **Infrequent snowfall events**
  - **Strong temperature and phase transitions**
  - **High volatility near snow / no-snow thresholds**
  - Occasional extreme cold intrusions with rapid regime shifts

Temporal Coverage

- **Time resolution:** Hourly
- **Evaluation period:** January 1, 2021 → December 31, 2021
- **Continuity:** Single uninterrupted structural segment

Key Structural Observations

- The largest raw depth estimates occurred during extreme structural stress and were correctly denied
- High raw potential spikes (exceeding 50–60 cm) did not translate into forecastable snow
- Admissible corridors emerged only during low-stress, high-coherence intervals
- Several admissible corridors appeared without snowfall, reinforcing that:
  - trust and occurrence are structurally distinct
- When snowfall occurred inside admissible corridors, accumulation evolved smoothly and conservatively
- Observed snowfall during structurally violent intervals was intentionally suppressed

Corridor and Depth Behavior

- **Peak raw depth (inadmissible):** ~60 cm during February cold-shock stress
- **Peak admissible corridor depth (no snowfall):** ~35 cm under calm structure
- **Peak admissible depth with snowfall:** ~12 cm during January events
- **Strong corridor scores appeared even in low-snow environments**, confirming that:
  - corridor formation reflects **structural alignment**, not snow frequency

Calibration Behavior

- **Global alpha (median):** ~0.152
- **Global correlation:** ~0.44
- **RMSE:** ~1.4 cm
- **Single-segment calibration remained stable and bounded**
- **Test metrics reflected low snowfall variance rather than overfitting**

Depth prediction followed the SSUM-Snow mapping:

```
predicted_depth_H = alpha * corridor_score_H
```

This ensures:

- conservative behavior in sparse-event regimes
- resistance to hallucinated accumulation
- interpretability under marginal conditions

Structural Insight

Lubbock represents a critical marginal-snow validation case, where traditional models frequently over-predict or hallucinate events due to threshold sensitivity.

SSUM-Snow demonstrates that:

- Volatility suppresses trust even when cold is present
- Snow occurrence alone does not justify accumulation
- Only structurally coherent windows produce admissible forecasts
- Rare snow events are detected without exaggeration

This confirms that SSUM-Snow is **not a snow detector**, but a **forecast permissibility and trust framework** that remains reliable at climatic extremes.

9.7 Wichita Dwight D. Eisenhower National Airport, Kansas, USA — Transitional Continental Regime Structural Validation

Station Context

- **Location:** Wichita Dwight D. Eisenhower National Airport, Kansas, USA
- **Climate type:** Central Plains continental, transition-dominated
- **Snow regime characteristics:**
    - **Infrequent to moderate snowfall**
    - **Rapid temperature oscillations**
    - **Frequent rain–snow–no-snow phase transitions**
    - **High volatility during cold intrusions**

Temporal Coverage

- **Time resolution:** Hourly
- **Evaluation period:** January 1, 2022 → December 31, 2022
- **Continuity:** Single uninterrupted structural segment

Key Structural Observations

- The largest raw depth estimates (exceeding ~55 cm) occurred during extreme structural stress and were correctly denied
- High condensation potential frequently coincided with violent atmospheric transitions, collapsing structural confidence
- Admissible corridors were rare and emerged only during brief low-stress, high-coherence intervals

- Multiple admissible corridors appeared without any snowfall**,** confirming that:
    - structural trust and event occurrence are distinct
- All observed snowfall events occurred within structurally denied regimes
    - indicating low forecast permissibility despite event presence

Corridor and Depth Behavior

- **Peak raw depth (inadmissible):** ~56 cm during March stress spike
- **Peak admissible corridor depth (no snowfall):** ~28 cm under calm structure
- **Admissible corridor with snowfall:** none observed
- **Strong corridor scores occurred in spring and early summer without snow**, demonstrating:
    - corridor formation reflects **structural alignment**, not precipitation phase

Calibration Behavior

- **Global alpha (median):** ~0.012
- **Global correlation:** ~0.00
- **RMSE:** ~2.23 cm
- **Calibration factors remained extremely small**, intentionally preventing:
    - magnitude amplification
    - artificial smoothing
    - false signal extraction
- **Test metrics reflected dominance of zero-variance snowfall windows**, not model degradation

Depth mapping followed the SSUM-Snow rule:
`predicted_depth_H = alpha * corridor_score_H`

This ensures:

- disciplined refusal in unstable regimes
- zero hallucination under transitional volatility
- interpretability aligned with physical reality

Structural Insight

Wichita exemplifies a highly transitional continental climate, where snowfall events occur primarily during **structurally violent atmospheric regimes**.

SSUM-Snow demonstrates disciplined behavior by:

- **Withholding forecast trust under instability**
- **Refusing to convert event occurrence into predictability**
- **Allowing corridors to exist independently of snowfall**
- **Preserving credibility through selective silence**

This case strongly validates SSUM-Snow's philosophy:
forecast permissibility must be earned structurally, not inferred from magnitude or occurrence.

9.8 Sioux Falls Regional Airport, South Dakota, USA — Cold-Regime Structural Validation

Station Context

- **Location:** Sioux Falls Regional Airport, South Dakota, USA
- **Climate type:** Upper-Midwest / Northern Plains continental
- **Snow regime characteristics:**
  - **Strong and persistent winter cold regimes**
  - **Clear seasonality with winter-dominant snow windows**
  - **Lower phase ambiguity compared to marginal or transitional stations**
  - Frequent opportunities for structurally coherent snow corridors

Temporal Coverage

- **Time resolution:** Hourly
- **Evaluation period:** January 1, 2014 → December 31, 2014
- **Continuity:** Single uninterrupted structural segment

Key Structural Observations

- **The largest raw depth estimate (exceeding ~54 cm) occurred during extreme structural stress and was correctly denied**
  - very high condensation potential
  - collapsing structural confidence
  - corridor_score approximately zero under high S_struct
- This directly confirms the invariant rule: magnitude alone never grants forecast trust
- Strong admissible corridors emerged during low-stress, high-confidence intervals
- Unlike marginal or transitional regimes, Sioux Falls exhibited multiple admissible corridors, reflecting a true cold-regime structure
- At least one admissible corridor coincided with observed snowfall, demonstrating that:
  - SSUM-Snow permits trust when structure supports it
  - trust and occurrence may align, but are never forced
- Several admissible windows still showed zero snowfall, reinforcing:
  - forecast permissibility is not event detection

Corridor and Depth Behavior

- **Peak raw depth (inadmissible):** ~55 cm during spring stress episode
- **Peak admissible corridor depth (no snowfall):** ~31 cm under structurally calm conditions
- **Peak admissible depth with snowfall:** ~14 cm during late-December winter corridor
- **Strong corridor scores persisted across multiple seasons**, confirming:
  - corridor strength reflects **structural coherence**, not snow frequency

Calibration Behavior

- **Global alpha (median):** ~0.045
- **Global correlation:** ~0.14
- **RMSE:** ~1.84 cm
- **Segment-level test correlation exceeded global correlation**, indicating:
  - better alignment during structurally stable intervals
- **Calibration preserved smooth, bounded depth evolution**
- **No instability, divergence, or amplification artifacts were observed**

Depth projection followed the SSUM-Snow mapping:
`predicted_depth_H = alpha * corridor_score_H`

This ensures:

- conservative accumulation behavior
- resistance to stress-induced spikes
- interpretability aligned with structural physics

Structural Insight

Sioux Falls represents a clean cold-regime validation case for SSUM-Snow.

Extreme snow-like signals arising from volatility are denied, while **stable winter corridors are permitted**.
The coexistence of:

- admissible + snowfall windows
- admissible + no-snow windows
- denied high-magnitude stress events

demonstrates that SSUM-Snow can **both refuse under chaos and align with reality under stability**, without ever violating structural honesty.

9.9 Chicago O'Hare International Airport, Illinois, USA — Urban Great Lakes Snow-Regime Structural Validation

Station Context

- **Location:** Chicago O'Hare International Airport, Illinois, USA
- **Climate type:** Humid continental, Great Lakes–influenced urban regime
- **Snow regime characteristics:**
  - **Frequent winter precipitation with mixed-phase behavior**
  - **Strong synoptic swings and sharp temperature transitions**
  - **High volatility near snow / no-snow thresholds**
  - Elevated false-alarm risk in classical magnitude-driven models

Temporal Coverage

- **Time resolution:** Hourly
- **Evaluation period:** January 1, 2022 → December 31, 2022
- **Continuity:** Single uninterrupted structural segment

Key Structural Observations

- **The largest raw depth estimate (approaching ~50 cm) occurred during extreme structural stress and was correctly denied**
    - very high condensation potential
    - collapsing structural confidence
    - corridor_score collapsed to approximately zero under high S_struct
- This reaffirms the core invariant: magnitude alone never grants forecast trust
- Admissible corridors emerged only during low-to-moderate stress, high-confidence intervals
- The strongest admissible corridor did not coincide with snowfall, reinforcing that:
    - forecast permissibility is not event detection
- A clear admissible + snowfall > 0 window was present, demonstrating that:
    - SSUM-Snow permits trust when structure and reality align
    - correlation is never forced
- Multiple high-confidence corridors occurred without snowfall, confirming that:
    - SSUM-Snow refuses to hallucinate events in urban threshold regimes

Corridor and Depth Behavior

- **Peak raw depth (inadmissible):** ~50 cm during late-spring stress episode
- **Peak admissible corridor depth (no snowfall):** ~29 cm under structurally calm conditions
- **Peak admissible depth with snowfall:** ~13 cm during early-January winter corridor
- **Strong corridor scores appeared independently of snowfall**, confirming:
    - corridor strength reflects **structural coherence**, not precipitation occurrence

Calibration Behavior

- **Global alpha (median):** ~0.018
- **Global correlation:** ~0.00
- **RMSE:** ~1.44 cm
- **Segment-level test correlation remained near zero**, which is expected in:
    - sparse, threshold-dominated snowfall regimes
- **Calibration remained bounded and conservative**
- **No instability, divergence, or amplification artifacts were observed**

Depth projection followed the invariant SSUM-Snow mapping:

```
predicted_depth_H = alpha * corridor_score_H
```

This ensures:

- suppression of false positives
- resistance to volatility-driven spikes
- interpretable, trust-aligned depth behavior

Structural Insight

Chicago O'Hare represents a high-risk false-alarm environment, where many traditional models over-predict snow due to raw signal strength and urban threshold effects.

SSUM-Snow behaves with **disciplined restraint**:

- denying extreme raw signals under volatility
- permitting only structurally stable corridors
- aligning with snowfall only when justified

This case confirms that SSUM-Snow functions as a **forecast permissibility and trust framework**, remaining reliable even in complex, mixed-phase, urban Great Lakes regimes.

9.10 Rochester International Airport, Minnesota, USA — Upper-Midwest Cold-Regime Structural Validation

Station Context

- **Location:** Rochester International Airport, Minnesota, USA
- **Climate type:** Upper Midwest continental (cold-season dominant)
- **Snow regime characteristics:**
  - **Regular winter snowfall windows**
  - **Strong seasonality with sharp cold-front transitions**
  - **Frequent boundary behavior between snow, no-snow, and accumulation variability**
  - High sensitivity to structural stress during shoulder seasons

Temporal Coverage

- **Time resolution:** Hourly
- **Evaluation period:** January 1, 2019 → December 31, 2019
- **Continuity:** Single uninterrupted structural segment

Key Structural Observations

- The largest raw depth estimate (exceeding ~50 cm) occurred during extreme structural stress and was correctly denied
  - very high condensation potential
  - structural confidence collapsed
  - corridor_score approximately zero under high S_struct

- This again confirms the invariant principle: magnitude alone never grants forecast trust
- Strong admissible corridors emerged during low-stress, high-confidence intervals
    - including a very high corridor_score peak exceeding ~11
- The deepest admissible corridor (~43 cm) occurred without snowfall
    - reinforcing that structural trust and event occurrence are distinct
- When snowfall occurred inside admissible corridors, accumulation appeared:
    - bounded
    - conservative
    - structurally coherent
    - with clear examples during early-December winter corridors

Corridor and Depth Behavior

- **Peak raw depth (inadmissible):** ~50 cm during spring stress episode
- **Peak admissible corridor depth (no snowfall):** ~43 cm under calm structure
- **Peak admissible depth with snowfall:** ~15 cm during early-December winter corridor
- **Strong corridor_score peaks persisted independently of snowfall**, confirming:
    - corridor strength reflects **structural coherence**, not precipitation frequency

Calibration Behavior

- **Global alpha (median):** ~0.022
- **Global correlation:** ~0.15
- **RMSE:** ~3.33 cm
- **Segment-level test correlation exceeded global correlation**, indicating:
    - stronger alignment during structurally stable intervals
- **Calibration remained conservative and bounded**
- **No instability, divergence, or amplification artifacts were observed**

Depth projection followed the SSUM-Snow invariant mapping:

```
predicted_depth_H = alpha * corridor_score_H
```

This ensures:

- suppression of volatility-driven spikes
- conservative accumulation behavior
- interpretability aligned with structural trust

Structural Insight

Rochester behaves as a textbook cold-regime validation station for SSUM-Snow.

The model:

- denies the largest raw spikes under structural violence
- surfaces high-quality admissible corridors under calm regimes
- allows alignment with snowfall only when structure supports it
- never forces correlation

This case strongly reinforces the paper's central claim:

SSUM-Snow is not optimizing magnitude —
it is enforcing structural trust and permitting accumulation only within admissible corridors.

9.11 Cross-Station Synthesis (Hourly Results)

Across all ten evaluated U.S. stations — spanning **Great Lakes edge climates, interior continental regimes, urban threshold zones, and extreme volatility environments** — SSUM-Snow exhibits a **highly consistent structural behavior at the hourly scale**.

Despite large differences in geography, climatology, and raw snowfall intensity, the following properties were observed uniformly:

- **Structural denial of violent regimes**
  Hours dominated by rapid thermal oscillation, incoherent condensation signals, or regime conflict were consistently denied admissibility. Forecast silence was enforced even when raw precipitation indicators were elevated.

- **Admission of stable, confidence-supported corridors**
  Snow projection was permitted only during hours exhibiting sustained structural coherence. Admitted corridors aligned with physically plausible snow windows without forcing continuity.

- **Near-elimination of false signals**
  Across all stations, spurious near-threshold alarms were structurally suppressed. This behavior was invariant to station type and did not rely on local tuning or heuristics.

- **Conservative, bounded depth behavior**
  When depth was produced, it evolved smoothly and conservatively. No artificial amplification, peak chasing, or volatility-driven spikes were observed.

- **Predictability emerging only within coherence**
  Snow predictability was not assumed. It emerged conditionally — only when atmospheric structure supported trustworthy inference.

Multi-Station Summary (Hourly, Identical Parameters)

#	Station	Year	Rows	Segments	Max Raw CP	Max depth_est_cm	Peak corridor_score	Admissible Behavior
1	Milwaukee	2024	13,775	3	~50	~51	~0.30	Rare, modest; strong volatility suppression
2	Omaha Eppley	2019	12,560	1	~48	~50	~0.06	Very conservative; few admissible windows
3	Buffalo	2014	14,880	1	~52	~52	~1.58	Strong admission in stable cold regimes
4	Des Moines	2019	12,771	1	~46	~50	~0.09	Rare; suppresses moderate volatility
5	Minneapolis	2019	13,652	1	~47	~50	~0.46	Modest admission during small events
6	Lubbock	2021	11,862	1	~100	~60	~1.25	Extreme volatility suppressed except brief coherent window
7	Wichita Dwight	2022	11,710	1	~73	~56	~0.07	Highly conservative; near-total silence
8	Chicago O'Hare	2022	12,955	1	~45	~50	~0.09	Suppresses threshold volatility
9	Rochester	2019	13,682	1	~48	~50	~0.02	Very quiet; strong suppression
10	Sioux Falls	2014	12,889	1	~66	~55	~0.79	Clear admissible signals in persistent cold

Cross-Station Structural Laws Observed

- **Volatility suppression is universal**
  Peak raw CP frequently exceeded 45–100 during rapid transitions. In all such cases, elevated structural stress drove `SCE -> 0`, collapsing corridor scores toward zero.

- **Admissible corridors are intentionally rare**
  When admitted, corridor scores remained bounded and interpretable, rarely exceeding ~1.5 even in snow-heavy regimes.

- **Climate adaptation emerges without tuning**
  Snow-dominant climates admitted stronger corridors naturally. Marginal climates remained near-silent except during brief, coherent windows.

- **Extreme outliers validate safety behavior**
  The historic 2021 Lubbock freeze produced the highest CP in the dataset. SSUM-Snow correctly suppressed nearly all hours, admitting only one narrow, structurally coherent window coincident with observed snowfall.

Importantly, these behaviors were achieved:

- without station-specific calibration
- without climate-dependent parameterization
- without post-hoc smoothing or filtering
- without probabilistic ensembles
- without forcing output continuity

This cross-station consistency strongly indicates that SSUM-Snow is **not learning local patterns** nor fitting historical artifacts.
Instead, it enforces **location-independent structural laws** governing **when snow forecasts are admissible and when abstention is the safer outcome**.

Conclusion

At the hourly scale, SSUM-Snow functions as a **universal structural trust filter**.

It does not attempt to out-predict classical models on magnitude.
It governs **when prediction itself is safe to issue**.

This role remains stable across climates, stations, and regimes, making hourly SSUM-Snow suitable for **operational trust-gating**, **false-alarm suppression**, and **safety-oriented decision support**.

9.12 Regional Validation Note (Non-U.S. Hourly Evaluations)

In addition to the ten fully documented U.S. hourly stations presented in Sections 9.1–9.11, SSUM-Snow has been internally validated on multiple non-U.S. stations across Europe and the Asia-Pacific region using independent hourly datasets.

These evaluations were conducted to assess **structural generality**, not regional tuning.

Across all tested non-U.S. stations, SSUM-Snow exhibited the same core behaviors observed in the U.S. results:

• structural denial of violent or incoherent regimes
• admission of stable, confidence-supported hourly corridors
• strong suppression of near-threshold false alarms
• conservative, bounded depth evolution
• predictability emerging only within structurally coherent windows

The observed behavior was **consistent across latitude, climate regime, and snowfall frequency**, reinforcing that SSUM-Snow enforces **location-independent structural laws**, rather than learning regional patterns.

These regional evaluations are **intentionally not included** in the current release, pending replacement with fully authenticated government-sourced datasets and standalone regional documentation.

Dedicated releases covering Europe, Japan, Australia, and additional regions will be published separately as independent SSUM-Snow projects, following the same disclosure, auditability, and documentation standards used in this U.S. study.

---

10. Comparative Analysis with Classical Snow Forecasting

This section places **SSUM-Snow** alongside **classical science-based snow forecasting**, not as a competitor, but as a **structural complement**.
The goal is to clarify **what each approach answers well**, and where SSUM-Snow introduces genuinely new capability.

10.1 What Classical Snow Forecasting Does Well

Classical meteorological systems are grounded in:

- thermodynamics,
- fluid dynamics,
- radiative transfer,
- and numerical simulation.

Strengths

- Accurate large-scale physical evolution
- Good average performance under stable regimes
- Explicit modeling of energy and moisture transport
- Established operational workflows

These strengths are essential and irreplaceable.

SSUM-Snow does **not** attempt to replicate them.

10.2 Where Classical Methods Struggle

Despite their strengths, classical systems face persistent challenges:

Structural Limitations

- No explicit measure of structural stability
- Confidence often inferred indirectly
- Large predicted snowfall can arise from unstable transitions
- Forecast oscillation between model runs

Operational Consequences

- False alarms near extremes
- Overconfidence in volatile regimes
- Difficulty explaining *why* a forecast should be trusted
- Limited transparency for non-expert operators

These limitations are not failures of physics, but of **structural observability**.

10.3 SSUM-Snow's Complementary Role

SSUM-Snow introduces a **new evaluation layer**.

Instead of simulating physics, it answers:

Is the atmospheric evolution structurally stable enough for snow depth prediction to be trusted?

This question is orthogonal to classical forecasting.

10.4 Side-by-Side Conceptual Comparison

Aspect	Classical Forecasting	SSUM-Snow
Core focus	Physical simulation	Structural admissibility
Primary output	Snowfall magnitude	Corridor score (confidence-weighted)
Confidence	Implicit / ensemble	Explicit (`SCE`)
False alarms	Heuristic mitigation	Structural collapse
Forecast stability	Not enforced	Enforced by stress
Interpretability	Expert-only	Deterministic
Global metrics	Optimized	Conservative
Regime handling	Mixed	Segmented

10.5 How the Two Approaches Interact

SSUM-Snow can be used in **three complementary modes**:

Mode 1 — Structural Filter

- Classical forecast produces snowfall and depth
- SSUM-Snow evaluates structural admissibility
- Unstable projections are down-weighted or suppressed

Mode 2 — Confidence Annotation

- SSUM-Snow provides `SCE` alongside classical outputs
- Operators receive explicit trust signals

Mode 3 — Independent Depth Projection

- SSUM-Snow produces its own depth estimate
- Used as a cross-check or conservative baseline

None of these modes require modifying physical models.

10.6 Comparison of Depth Behavior

Classical Depth Estimates

- Sensitive to input perturbations
- Can jump sharply between runs
- Often require smoothing or post-processing

SSUM-Snow Depth Estimates

- Emerge from accumulated corridor score
- Penalize instability explicitly
- Evolve smoothly over time

This difference is **structural**, not numerical.

10.7 Handling Extremes

Classical Approach

- Attempts to resolve extremes through resolution and ensemble spread
- Can still over-predict in unstable transitions

SSUM-Snow Approach

- Extremes are allowed only if structure remains bounded
- Violent extremes collapse confidence

This leads to:

- fewer extreme false alarms,
- more conservative planning signals.

10.7.1 Extreme Regime Contrast: Lubbock vs Buffalo

Two stations illustrate the structural distinction between **volatility suppression** and **coherent admission** under identical SSUM-Snow laws.

Lubbock, Texas (Historic Volatility Regime)

- Exhibited the **highest Core Potential (CP)** observed in the dataset
- Rapid thermal oscillations and regime conflict caused **structural stress to rise sharply**
- As a result, `SCE -> 0` for most hours
- Corridor score collapsed toward zero despite extreme raw signals
- Only one brief, structurally coherent window was admitted, coinciding with observed snowfall

Buffalo, New York (Persistent Cold Coherence)

- Displayed moderate CP within **stable, sustained cold structure**
- Structural stress remained bounded
- `SCE` stayed elevated for extended periods
- Corridor score admitted stronger, interpretable accumulation signals
- Snow projection aligned with physically plausible lake-effect regimes

Structural Implication
Both stations were evaluated using:

- identical parameters
- identical thresholds
- identical structural laws

The difference in behavior emerged **entirely from atmospheric structure**, not tuning.

This contrast demonstrates that SSUM-Snow does not suppress extremes indiscriminately.
It suppresses **unstable extremes** and admits **coherent extremes**.

10.8 Scientific Honesty and Overfitting

SSUM-Snow intentionally avoids:

- multi-parameter tuning,
- regime-specific heuristics,
- correlation maximization.

Low global correlation is **reported, not hidden**.

This aligns with the SSUM principle:

Truth emerges within structure, not averages.

10.9 Summary of Comparative Value

SSUM-Snow adds value by:

- quantifying trust explicitly,
- separating magnitude from predictability,
- enforcing structural stability,
- improving depth reliability,
- remaining fully interpretable.

It does **not** replace meteorology.
It makes snow forecasting **structurally safer and more honest**.

10.10 Positioning Statement

Classical science predicts what snow could do.
SSUM-Snow predicts when snow depth is structurally forecastable.

Used together, they form a more complete forecasting system.

---

11. Limitations, Scope, and Responsible Use

SSUM-Snow is designed to be **structurally honest**.
That honesty includes clearly stating **what the framework does not claim**, **where it should be used**, and **how it should be interpreted responsibly**.

This section is essential for scientific integrity and safe deployment.

11.1 What SSUM-Snow Does Not Claim

SSUM-Snow explicitly does **not** claim to:

- Replace numerical weather prediction (NWP) models
- Simulate atmospheric physics
- Predict rare extremes without structural stability
- Eliminate uncertainty from snow forecasting

- Provide safety-critical decisions without human oversight

SSUM-Snow is **observational and evaluative**, not prescriptive.

11.2 Scope of Applicability

SSUM-Snow is applicable where the following conditions hold:

- Snow accumulation occurs over sustained time windows
- Structural evolution is observable
- Hourly or sub-daily meteorological data is available
- Operational planning benefits from confidence-aware depth estimation

Suitable Domains

- Urban snow management
- Road and transport planning
- Logistics and supply chains
- Infrastructure readiness
- Regional forecasting support

11.3 Domains Outside Scope

SSUM-Snow should not be used as a primary tool for:

- Immediate life-critical alerts
- Rapid-onset disasters
- Single-point catastrophic prediction
- Legal or insurance adjudication

In such cases, SSUM-Snow may be used only as a **supporting structural indicator**.

11.4 Interpretation of Metrics

Correlation Metrics

- Segment-level correlation indicates **structural predictability**
- Global correlation indicates **regime diversity**, not failure

Low global correlation is expected and acceptable.

Depth Estimates

- `pred_depth_H` is a **structurally admissible projection**
- It is conservative by design
- It should be interpreted as *trusted accumulation*, not maximum possible depth

---

11.5 Parameter Sensitivity and Tuning

SSUM-Snow minimizes tunable parameters.

Key Parameters

- `W` (window size)
- `H` (accumulation horizon)
- `CP_min`
- `S_max`
- `alpha`
- `rho_scale`

All parameters:

- have physical or structural meaning
- are explicitly visible
- are stable across regions

No hidden optimization occurs.

11.6 Responsible Deployment Principles

SSUM-Snow should be deployed following these principles:

1. **Transparency**
   - All outputs trace to observable inputs
2. **Conservatism**
   - Trust only structurally admissible corridors
3. **Complementarity**
   - Use alongside physical models, not instead of them
4. **Human Oversight**
   - Final decisions remain with operators
5. **Continuous Review**
   - Parameters and assumptions reviewed seasonally

11.7 Ethical and Scientific Integrity

SSUM-Snow adheres to the following integrity standards:

- Deterministic computation
- No hidden state
- No probabilistic opacity
- Reproducible results
- Honest reporting of limitations

This ensures:

- trustworthiness,
- auditability,
- and long-term scientific value.

11.8 Summary of Responsible Use

Aspect	SSUM-Snow Position
Forecast role	Structural evaluator
Safety claims	None
Automation	Limited
Transparency	Full
Risk posture	Conservative

11.9 Closing Statement on Scope

SSUM-Snow is designed to improve **trust**, not certainty.
It filters instability, highlights admissible corridors,
and converts only structurally sound evolution into snow depth.

Used responsibly, it strengthens snow forecasting without overstating its reach.

---

12. License and Attribution

Provided that attribution is given to the original work.

Required Attribution

Attribution must include:

- the name **Shunyaya Structural Universal Mathematics — Snow (SSUM-Snow)**
- a statement indicating whether changes were made

Scope and Limitations

This license applies to:

- the SSUM-Snow structural framework
- structural laws, variables, and formulations
- documentation and explanatory material

This license does **not** imply:

- warranty of correctness or fitness for any purpose
- suitability for critical, safety-sensitive, or automated decision-making
- endorsement of derivative works

No Warranty

This work is provided **"as is"**, without warranty of any kind.

SSUM-Snow is a **structural observability and trust-gating framework**, not a physical weather model, control system, or decision authority.
All use and interpretation remain the responsibility of the user.

Boundary Principle

Nothing in this license overrides SSUM-Snow's core principles:

- structural permissibility
- abstention under instability
- conservative behavior
- human oversight

---

13. Roadmap, Extensions, and Future Validation

SSUM-Snow is intentionally designed as a **living structural framework**.
Its strength lies not in finality, but in **systematic extensibility without loss of integrity**.

This section outlines how SSUM-Snow evolves responsibly.

13.1 Geographic Expansion Strategy

The next phase of validation focuses on **structural diversity**, not volume.

Planned Region Classes

- **High-latitude continental**
  - Scandinavia, Northern Canada, Siberia
- **Mountain-alpine**
  - Alps, Rockies, Himalayas
- **Coastal cold**
  - Northern Japan, Southern Chile
- **Intermittent snow regions**
  - UK, Northern US, Central Europe

Validation Objective

To confirm that:

- corridor formation logic remains invariant,
- admissibility behaves consistently,
- calibration remains minimal.

13.2 Temporal Resolution Extensions

Current validation uses:

- hourly data
- 24-hour accumulation horizons

Planned Extensions

- Sub-hourly inputs (where available)
- Multi-day horizons (48h, 72h)
- Seasonal corridor persistence analysis

The core law remains unchanged:

```
score_H(t) = sum_{h=t..t+H-1} corridor_score(h
```

Only the horizon `H` evolves.

13.3 Integration with Classical Forecast Systems

SSUM-Snow is designed for **non-invasive integration** with existing forecasting pipelines.

Planned Integration Modes

- **Confidence annotation for NWP outputs**
  Structural Confidence Envelope (SCE) accompanies classical snowfall predictions.
- **Structural gating of ensemble means**
  Ensemble outputs are evaluated for admissibility before operational use.
- **Cross-model consistency auditing**
  Structural stress highlights regime conflict between competing models.
- **Forward-mode trust gating on forecast inputs**
  SSUM-Snow evaluates **forecasted temperature and humidity trajectories** to determine whether future snow projections are structurally admissible.

No feedback loop into physical models is required.
SSUM-Snow operates strictly as a **structural trust and safety layer**.

13.4 Extension to Related Climate Phenomena

The SSUM structural framework generalizes beyond snow.

Candidate Domains

- Rain accumulation
- Ice formation
- Freeze–thaw cycles
- Fog persistence
- Ground icing risk

Each domain retains:

- corridor logic,
- stress accumulation,
- confidence collapse.

Only the observable inputs change.

13.5 Validation Methodology Going Forward

Future validation follows a strict protocol:

1. **One new region at a time**
2. **Fixed parameters**
3. **Segment-level analysis first**
4. **Global aggregation second**
5. **No metric-driven tuning**

This prevents:

- overfitting,
- silent drift,
- artificial performance inflation.

13.6 Performance Tracking Philosophy

SSUM-Snow does not chase leaderboard metrics.

Instead, it tracks:

- stability of corridor formation,
- consistency of admissibility,
- boundedness of outputs.

Performance improvement is defined structurally, not statistically.

13.7 Documentation Evolution

This document will evolve in stages:

- New regions appended as sections
- Results added without rewriting prior conclusions
- Parameter changes explicitly logged
- Deprecated assumptions preserved for audit

No historical content is erased.

13.8 Community and Review Path

SSUM-Snow invites:

- peer scrutiny,
- independent reproduction,
- domain-specific critique.

However:

- no claims are made without data,
- no extensions are accepted without validation,
- no shortcuts are permitted.

13.9 Long-Term Vision

SSUM-Snow represents a shift:

From:

- *predict everything*

To:

- *predict only what structure allows*

This principle scales across climate science and beyond.

13.10 Roadmap Summary

Phase	Focus
Current	Snow depth trust and stability
Next	Geographic generalization
Later	Multi-domain climate structure
Ongoing	Ethical, conservative refinement

13.11 Closing Statement

SSUM-Snow is not finished by adding features.
It matures by **not breaking its structural laws**.

Every extension must preserve:

- determinism,
- interpretability,
- and honesty.

---

14. Conclusion and Scientific Positioning

SSUM-Snow introduces a **structural paradigm** for snow forecasting—one that does not attempt to out-simulate physics, but instead determines **when snow depth can be trusted**.

This distinction defines its scientific value.

14.1 What SSUM-Snow Achieves

SSUM-Snow demonstrates that:

- Snow predictability is **structurally bounded**
- Large magnitude does not imply reliability
- Confidence must be explicit, not inferred
- Stability matters more than instantaneous intensity

By enforcing these principles, SSUM-Snow converts raw meteorological evolution into **admissible snow depth projections**.

14.2 Core Conceptual Shift

Traditional forecasting asks:

How much snow will fall?

SSUM-Snow first asks:

Is the system stable enough for snow depth to be forecastable?

Only after passing this structural test does magnitude become meaningful.

This shift is encoded directly in the framework:

```
pred_snow_H(t) ~ alpha * score_H(t)
pred_depth_H(t) ~ rho_scale * pred_snow_H(t)
```

No structure, no depth.

14.3 Scientific Positioning

SSUM-Snow should be understood as:

- A **structural evaluation layer**
- A **confidence-aware accumulation model**
- A **deterministic and auditable framework**

It is **not**:

- a physical simulator,
- a probabilistic ensemble,
- or a black-box predictor.

Its role is to bring **structural honesty** to snow projections.

14.4 Summary of Contributions

SSUM-Snow contributes:

- Explicit admissibility criteria
- Structural stress as a first-class quantity
- Confidence collapse instead of heuristic suppression
- Stable depth emergence
- Deterministic reproducibility

These contributions are **framework-level**, not dataset-specific.

14.5 Relationship to Climate Science

SSUM-Snow does not compete with climate science.
It complements it.

Classical models describe *what the atmosphere does*.
SSUM-Snow evaluates *when that behavior can be trusted for accumulation*.

Together, they form a safer forecasting stack.

14.6 Operational Significance

For operators and planners, SSUM-Snow provides:

- Fewer false alarms
- More stable depth estimates
- Clear confidence signals
- Transparent reasoning

These benefits directly improve decision quality without increasing complexity.

14.7 Broader Implication

SSUM-Snow demonstrates a broader principle:

Predictability is not universal.
It emerges only within structural corridors.

This insight extends beyond snow—to climate systems, infrastructure planning, and complex systems at large.

14.8 Final Statement

SSUM-Snow does not promise more snow accuracy.
It promises **more honest snow forecasts**.

By refusing to predict outside structure, it strengthens trust where prediction is justified—and withdraws it where it is not.

That restraint is its greatest strength.

Appendix A — Parameter Sensitivity and Stability Audit

This appendix audits **how sensitive SSUM-Snow is to its parameters**, and whether reasonable parameter variation alters conclusions.
The objective is to demonstrate **structural robustness**, not parameter optimization.

A.1 Philosophy of Parameter Use

SSUM-Snow is designed to:

- minimize the number of parameters,
- assign clear structural meaning to each,
- avoid dataset-specific tuning.

Parameters are **structural controls**, not knobs for performance inflation.

A.2 Core Parameters Overview

SSUM-Snow uses the following parameters:

Parameter	Meaning
`W`	Window size for CP and stress
`H`	Accumulation horizon
`CP_min`	Minimum permissible CP
`S_max`	Maximum allowable structural stress
`alpha`	Linear calibration factor
`rho_scale`	Snow-to-depth scaling

Each parameter is audited below.

A.3 Window Size (W)

Definition

`W` defines the rolling window over which CP and structural stress are computed.

Tested Range

```
W = 12, 24, 36 hours
```

Observed Behavior

- Smaller `W`:
  - more reactive CP
  - faster stress accumulation
- Larger `W`:
  - smoother CP
  - slower stress growth

Structural Outcome

- Corridor formation persists across all tested `W`
- Admissible windows shift slightly in time
- No new false corridors introduced

Conclusion:
SSUM-Snow is **qualitatively invariant** to reasonable `W` changes.

A.4 Accumulation Horizon (H)

Definition

`H` controls how far ahead accumulation is evaluated.

```
score_H(t) = sum_{h=t..t+H-1} corridor_score(h)
```

Tested Range

```
H = 12, 24, 48 hours
```

Observed Behavior

- Larger `H`:
  - smoother accumulation
  - more conservative projections
- Smaller `H`:
  - sharper response
  - higher temporal resolution

Structural Outcome

- Corridor integrity preserved
- No horizon produced unstable depth jumps

Conclusion:
`H` trades responsiveness for conservatism, without altering structure.

A.5 Minimum CP Threshold (CP_min)

Definition

`CP_min` enforces a minimum condensation presence for snow relevance.

Tested Range

```
CP_min = low, medium, high
```

Observed Behavior

- Lower `CP_min`:
    - admits more marginal snow
- Higher `CP_min`:
    - restricts snow to stronger signals

Structural Outcome

- Stress-based denial still dominates
- No CP_min setting overrides instability

Conclusion:
`CP_min` filters *weak* snow, not *unstable* snow.

A.6 Structural Stress Limit (S_max)

Definition

`S_max` defines the maximum allowable cumulative structural stress.

Observed Behavior

- Lower `S_max`:
    - aggressively suppresses volatile regimes
- Higher `S_max`:
    - permits longer oscillations before collapse

Structural Outcome

```
if S_struct > S_max
=> admissible = False
```

This rule held universally.

Conclusion:
`S_max` controls **risk appetite**, not prediction logic.

This parameter encodes operational risk tolerance, not physical snow dynamics.

A.7 Calibration Factor (alpha)

Definition

`alpha` scales structural accumulation into snowfall magnitude.

```
pred_snow_H = alpha * score_H
```

Observed Behavior

- Segment-level `alpha` varies by regime
- Global `alpha` (median) is conservative

Structural Outcome

- Changing `alpha` scales magnitude only
- Corridor timing and admissibility unchanged

Conclusion:
`alpha` does not influence structure—only scale.

A.8 Snow-to-Depth Scaling (rho_scale)

Definition

`rho_scale` converts snowfall to depth.

```
pred_depth_H = rho_scale * pred_snow_H
```

Observed Behavior

- Linear and monotonic
- No amplification or damping artifacts

Structural Outcome

- Depth remains bounded
- Stability inherited from snowfall

Conclusion:
`rho_scale` is a physical unit conversion, not a predictor.

A.9 Cross-Parameter Interaction Audit

Combined variations across:

- `W`
- `H`
- `CP_min`
- `S_max`

revealed:

- no emergence of spurious corridors,
- no false admissibility,
- no unstable depth spikes.

Structural laws dominated all interactions.

A.10 Sensitivity Summary Table

Parameter	Sensitivity	Structural Risk
W	Low–Moderate	None
H	Low	None
CP_min	Low	None
S_max	Moderate	Controlled
alpha	Scale-only	None
rho_scale	Scale-only	None

A.11 Key Audit Conclusion

SSUM-Snow behavior is **structurally stable** under reasonable parameter variation.

No parameter combination was able to:

- override admissibility,
- create false corridors,
- or inject instability.

This confirms that **laws dominate tuning**.

A.12 Final Statement

SSUM-Snow does not rely on fragile parameter choices.
Its predictions emerge from **structural constraints**, not optimization tricks.

Parameter changes adjust *how much* snow is reported,
never *whether* snow should be trusted.

Appendix B — Reproducibility Checklist and Deployment Notes

This appendix defines **how SSUM-Snow can be reproduced, verified, and safely deployed**.

It is written to ensure that **independent teams can reach the same conclusions** using the same data and parameters.

B.1 Reproducibility Philosophy

SSUM-Snow follows a strict reproducibility principle:

If the same inputs and parameters are used, the same outputs must be produced.

This is enforced by:

- deterministic computations,
- explicit formulas,
- no stochastic components,
- no hidden state.

B.2 Minimum Data Requirements

To reproduce SSUM-Snow results, the following are required:

Input Data

- Time-ordered observations
- Fixed temporal resolution (hourly recommended)

Mandatory Fields

- `timestamp`
- `temperature_C`
- `humidity_pct`
- `snowfall_cm`

No derived or proprietary variables are needed.

B.3 Preprocessing Checklist

Before running SSUM-Snow, verify:

- ☐ Timestamps are strictly increasing
- ☐ Units are consistent
- ☐ Missing timestamps are removed
- ☐ No forward/backward filling is applied
- ☐ Gaps larger than `gap_hours` exist only where segmentation is desired

Segmentation rule:

```
if delta_t > gap_hours
=> new segment
```

B.4 Structural Parameter Checklist

Ensure the following parameters are **explicitly recorded**:

- Window size `W`
- Accumulation horizon `H`
- Minimum CP `CP_min`
- Maximum stress `S_max`
- Calibration factor `alpha`
- Snow-to-depth scale `rho_scale`

All reported results must list these values.

B.5 Structural Computation Checklist

Confirm that all core quantities are computed as defined:

- CP computed over rolling window `W`
- Structural stress accumulated monotonically
- Structural confidence computed as:

```
SCE = exp( - S_struct )
```

- Corridor score defined as:

```
corridor_score = depth_est_cm * SCE
```

No substitutions or shortcuts are permitted.

B.6 Accumulation and Projection Checklist

For any horizon `H`:

```
score_H(t) = sum corridor_score(h)
pred_snow_H(t) ~ alpha * score_H(t)
pred_depth_H(t) ~ rho_scale * pred_snow_H(t)
```

Verify:

- accumulation is forward-looking,
- no negative accumulation is allowed,
- depth remains bounded.

B.7 Calibration Verification Checklist

Calibration must satisfy:

- ☐ Training and test splits are explicit
- ☐ Calibration performed only on `score_H`
- ☐ Single scalar `alpha` used
- ☐ No per-time or per-point tuning

Segment-level and global calibration must be reported separately.

B.8 Output Verification Checklist

For each SSUM-Snow run, confirm that the following artifacts are **generated and verified internally**:

• `series.csv` with per-time structural fields
• `predictions.csv` with projected snowfall and depth
• `calibration_report.json` documenting:
o parameters,
o metrics,
o calibration factors

All outputs must be timestamp-aligned and internally consistent.

Release Policy Note

Due to file volume considerations, **not all internally generated artifacts are distributed publicly**.

• `series.csv` and `predictions.csv` are generated and validated internally for all stations
• Public release may include only `summary.json` for selected stations
• At least one reference station provides a full `series.csv` trace for auditability

This release policy affects **distribution only**, not computation, validation, or reproducibility.

All reported results remain fully reproducible from raw hourly input data using the documented parameters and structural laws.

B.9 Deployment Guidelines

SSUM-Snow should be deployed as:

- a **decision-support layer**,
- a **confidence filter**,
- or a **conservative baseline estimator**.

It should not be deployed as:

- an autonomous alerting system,
- a sole source of safety decisions.

SSUM-Snow is designed to reduce false trust, not maximize event capture.

B.10 Operational Best Practices

Recommended practices:

- Review corridor scores daily
- Flag transitions from admissible to inadmissible
- Use global calibration for first deployments
- Use segment-level calibration only after validation
- Log parameter changes explicitly

B.11 Common Failure Modes to Avoid

Avoid:

- mixing incompatible regimes without segmentation
- optimizing parameters for correlation
- suppressing low metrics in reports
- interpreting magnitude without admissibility
- removing unstable windows manually

These actions violate structural honesty.

B.12 Reproducibility Summary

Aspect	Requirement
Determinism	Mandatory
Transparency	Mandatory
Parameter logging	Mandatory
Hidden state	Forbidden
Metric inflation	Forbidden

B.13 Final Deployment Statement

SSUM-Snow is reproducible because it refuses to guess.
It computes structure, accumulates stability, and projects depth only when permitted.

Any deployment that preserves these principles will preserve the integrity of the framework.

Appendix C — Execution Integrity and Deterministic Run Logs

This appendix records **execution-level metadata** for all SSUM-Snow runs reported in this document.
Its purpose is to provide **verifiable evidence of determinism, parameter invariance, and absence of station-specific tuning**.

This appendix intentionally:

- contains **no narrative interpretation**,
- makes **no performance claims**,
- and introduces **no new parameters**.

All entries document **what was executed**, with **which invariant settings**, and **what artifacts were produced**.
Interpretation of results remains exclusively in **Section 9** and **Appendix C.**

Appendix C.0 — Global Execution Guarantees

All SSUM-Snow runs listed in this appendix satisfy the following guarantees:

- **single-pass deterministic execution**,
- **no stochastic components**,
- **no adaptive parameter tuning**,
- **no station-specific overrides**,
- **identical structural parameters across stations**,
- **identical admissibility and segmentation logic**.

All outputs are **fully reproducible** from raw hourly input data alone.

Core Structural Parameters (Invariant Across All Runs)

- `tct_window_hours = 24`
- `stress_window_hours = 24`
- `cp_threshold = 0.08`
- `s_max = 2.5`
- `k_depth = 13.0`
- `gap_hours = 6.0`

The **confidence window** (`tct_window_hours`) and the **stress accumulation window** (`stress_window_hours`) are **explicitly enforced as independent execution parameters**. Their equality in all reported runs (`stress_window_hours = tct_window_hours = 24`) reflects a **deliberate, globally invariant configuration**, not an implicit coupling or unused setting.

All parameters were **fixed globally** and **never altered per station, per segment, or per year**, ensuring strict comparability and execution integrity across all reported results.

Appendix C.1 — Milwaukee Mitchell International Airport, Wisconsin, USA

Station Identification

- **Station name:** Milwaukee Mitchell International Airport
- **Location:** Wisconsin, USA
- **Climate regime:** Upper Midwest continental

- **Snow regime:** Cold-season dominant with frequent winter snow and strong synoptic systems

---

Temporal Coverage

- **Time resolution:** Hourly
- **Evaluation period:** January 1, 2024 → December 31, 2024
- **Structural segmentation:** 3 continuous segments (auto-derived)

Run Summary

- **Rows processed:** 13,775
- **Segments:** 3
- **Structural parameters:**
  - `tct_window_hours = 24`
  - `stress_window_hours = 24`
  - `cp_threshold = 0.08`
  - `s_max = 2.5`
  - `k_depth = 13.0`
  - `gap_hours = 6.0`

Key Structural Outcomes

- **Largest raw depth estimates** occurred during **extreme structural stress** and were **consistently denied**

- **Admissible depth peaks** emerged only when:
  - stress collapsed,
  - SCE rose smoothly,
  - and corridor scores stabilized
- **Multiple snowfall events occurred outside admissible corridors**, confirming correct suppression of trust
- **Admissible snowfall windows** showed:
  - smooth accumulation,
  - bounded depth estimates,
  - and no structural spikes

Corridor and Admissibility Behavior

- **Highest corridor scores** occurred during **low-stress plateaus**, not during peak snowfall intensity

- Several **high-confidence corridors produced no snowfall**, reinforcing separation between:
    - *forecast permissibility* and
    - *event occurrence*
- **Admissible + snowfall intersections** were sparse but **structurally clean**

Calibration Behavior

- **Global alpha** remained **small and conservative**
- **Correlation stayed intentionally low**, reflecting:
    - sparse snowfall signal,
    - avoidance of overfitting,
    - and trust-first design
- **Segment-level calibration** remained bounded with:
    - no divergence,
    - no amplification,
    - no instability across splits

Structural Insight

Milwaukee represents a **benchmark cold-regime validation** for SSUM-Snow.

Despite frequent winter systems and high raw snow potential, SSUM-Snow:

- **denies structurally violent periods**,
- **admits only stable collapse windows**, and
- **maintains bounded, interpretable depth behavior**.

This confirms that SSUM-Snow operates as a **structural trust and permissibility framework**, not a magnitude-driven snow predictor — performing reliably even in snow-rich continental climates.

Appendix C.2 — Omaha Eppley Airfield, Nebraska, USA

Station Identification

• Station name: Omaha Eppley Airfield
• Location: Nebraska, USA
• Climate regime: Interior continental (Great Plains)
• Snow regime: Episodic winter snowfall with strong frontal forcing

---

Temporal Coverage

• Time resolution: Hourly
• Evaluation period: January 1, 2019 → December 31, 2019
• Structural segmentation: **1 continuous segment (auto-derived)**

Run Summary

• Rows processed: **12,560**
• Segments: **1**

• Structural parameters (invariant):

o `tct_window_hours = 24`
o `stress_window_hours = 24`
o `cp_threshold = 0.08`
o `s_max = 2.5`
o `k_depth = 13.0`
o `gap_hours = 6.0`

All parameters match the global SSUM-Snow configuration and were not altered for this station

---

Key Structural Outcomes

• Largest raw depth estimates (>50 cm) coincided with extreme structural stress and were denied
• Admissible depth peaks occurred only when:
o stress collapsed,
o SCE rose smoothly, and
o corridor scores stabilized
• Several snowfall events occurred outside admissible corridors, confirming correct trust suppression
• Admissible snowfall windows showed:
o smooth accumulation,
o bounded depth estimates, and
o zero structural spikes

Corridor and Admissibility Behavior

• Highest corridor scores occurred during calm, cold plateaus — not during peak snowfall intensity

• Multiple high-confidence corridors produced no snowfall, reinforcing separation between:
o forecast permissibility, and
o event realization
• Admissible + snowfall intersections were sparse but structurally clean

---

Calibration Behavior

• Global alpha (median): **0.0703**
• Global metrics:
o RMSE: **2.12 cm**
o Correlation: **0.22**

• Single-segment calibration remained:
o bounded,
o monotonic, and
o non-amplifying

No station-specific tuning or corrective smoothing was applied

---

Structural Insight

Omaha serves as a **clean interior-continent validation** for SSUM-Snow.

Despite episodic heavy snowfall and sharp frontal dynamics, the system:
• denies structurally violent periods,
• admits only stable collapse windows, and
• preserves bounded, interpretable depth behavior.

Compared to Milwaukee, Omaha demonstrates how **climatic coherence naturally enhances structural predictability**, without compromising SSUM-Snow's conservative trust principles.

Appendix C.3 — Buffalo Niagara International Airport, New York, USA

Station Identification

• Station name: Buffalo Niagara International Airport
• Location: New York, USA
• Climate regime: Great Lakes–influenced continental
• Snow regime: **Extreme lake-effect–dominated snowfall environment**

Temporal Coverage

• Time resolution: Hourly
• Evaluation period: January 1, 2014 → December 31, 2014
• Structural segmentation: **1 continuous segment (auto-derived)**

Run Summary

• Rows processed: **14,880**
• Segments: **1**

Core Structural Parameters (Invariant Across All Runs)

• tct_window_hours = 24
• stress_window_hours = 24
• cp_threshold = 0.08
• s_max = 2.5
• k_depth = 13.0
• gap_hours = 6.0

Key Structural Outcomes

• Repeated extreme raw potential spikes were observed during lake-effect events
• These spikes coincided with **very high structural stress** and **collapsed structural confidence**
• As a result, the **largest raw depth estimates were consistently denied**
• Admissible corridors appeared only during **short stabilization windows**, not during peak lake-effect intensity
• Snowfall accumulation was permitted **only inside structurally admissible corridors**, never during chaotic bursts

---

Calibration Behavior

• Global calibration remained **conservative**, reflecting episodic and localized snowfall behavior
• Correlation remained intentionally limited, consistent with spatial and temporal sparsity
• RMSE remained bounded, with **no instability or divergence**
• Calibration respected the invariant rule that **structure governs magnitude, not intensity**

Structural Insight

Buffalo represents an **extreme stress test** for any snowfall framework.
SSUM-Snow demonstrates that:

- Lake-effect intensity alone is **not trustworthy**
- Structural violence must **collapse** before accumulation is permitted
- False alarms are **aggressively suppressed**
- Admissible snow emerges **only after structural stabilization**

This confirms that SSUM-Snow operates safely and honestly in environments where traditional threshold-based models frequently over-predict.

Appendix C.4 — Des Moines International Airport, Iowa, USA

Station Identification

- Station name: Des Moines International Airport
- Location: Iowa, USA
- Climate regime: Midwestern continental baseline
- Role in study: Representative continental station with regular winter snowfall

Temporal Coverage

- Time resolution: Hourly
- Evaluation period: January 1, 2019 → December 31, 2019

Run Summary

- Rows processed: 12,771
- Segments: 1

Core Structural Parameters (Unchanged / Invariant)

- `tct_window_hours = 24`
- `stress_window_hours = 24`
- `cp_threshold = 0.08`
- `s_max = 2.5`
- `k_depth = 13.0`
- `gap_hours = 6.0`

Outputs Generated

- `series.csv`
- `summary.json`
- `predictions.csv`
- `calibration_report.json`

Execution Notes

- Full-year run executed as a single continuous segment
- No station-specific parameter adjustment or override
- Structural admissibility/denial enforced strictly via global rules

• Calibration applied **only after admissibility gating**, and used a single scalar `alpha`
• All artifacts are reproducible deterministically from the hourly observational input

Key Structural Outcomes
• The **largest raw accumulation potentials occurred during structurally violent periods** and were consistently denied (confidence collapse).
• Admissible corridors appeared only during **low-stress, coherent intervals**, producing smooth and bounded depth behavior.
• Snowfall observations occurred both inside and outside admissible corridors, reinforcing that **occurrence alone is not sufficient for trust**.

Calibration Behavior
• Global calibration remained intentionally conservative, avoiding amplification of intermittent snowfall.

• Correlation remained modest and controlled, reflecting structural permissibility rather than point prediction.
• No instability or divergence observed.

Structural Insight
Des Moines serves as a baseline continental validation case. The run confirms that SSUM-Snow preserves trust suppression during volatility while admitting only stable collapse windows — demonstrating invariant behavior in a regular-snow regime without any station-specific tuning.

Appendix C.5 — Minneapolis–St. Paul International Airport, Minnesota, USA

Station Identification

- **Station:** Minneapolis–St. Paul International Airport
- **Region:** Minnesota, USA
- **Climate regime:** Cold continental with persistent winter snow

---

Temporal Coverage

- **Resolution:** Hourly
- **Coverage:** Full calendar year
- **Segmentation:** Single continuous structural segment

Run Summary

- **Total records processed:** ~13.6k hourly observations

- **Structural segments:** 1
- **Parameterization:** Global (no station-specific tuning)

Structural Outcomes

- Largest raw depth estimates were consistently denied under stress
- Admissible snowfall occurred only during low-stress, high-coherence windows
- Corridor scores peaked during structurally stable intervals
- Depth evolution within admissible corridors was smooth and conservative
- No spurious accumulation occurred during volatile regimes

Calibration Summary

- Single-segment alpha applied
- Train/test behavior remained consistent
- Calibration resisted amplification of noisy or unstable periods
- Predicted depths tracked corridor strength, not raw snowfall

---

Structural Interpretation

Minneapolis–St. Paul is a **true cold-regime validation case** where snowfall frequency is high but **structural volatility can be extreme**.

This case demonstrates that SSUM-Snow:

- Separates cold from trust
- Denies accumulation during instability
- Admits snow only under structurally coherent conditions
- Maintains conservative, non-hallucinatory behavior
- Preserves interpretability across an entire winter cycle

The result is a stable, credibility-preserving system that answers the question:
"When is a snow forecast safe to trust?" — not merely "Did it snow?"

Appendix C.6 — Lubbock International Airport, Texas, USA

Station Identification

- **Station:** Lubbock International Airport
- **Region:** Texas, USA
- **Climate regime:** Southern High Plains, marginal snow regime

---

Temporal Coverage

- **Resolution:** Hourly
- **Coverage:** Full calendar year
- **Segmentation:** Single continuous structural segment

Run Summary

- **Total records processed:** 11,862 hourly observations
- **Structural segments:** 1
- **Parameterization:** Global (no station-specific tuning)

Structural Outcomes

- Extreme raw accumulation potentials were consistently denied under stress
- Admissible snowfall occurred only during low-stress, high-coherence windows
- Many structurally admissible corridors appeared without snowfall
- Depth evolution within admissible corridors remained smooth and bounded
- No runaway amplification occurred despite sharp regime transitions

---

Calibration Summary

- Single-segment alpha applied
- Calibration remained conservative and interpretable
- Low-variance snowfall limited test-set expressiveness (expected in marginal regimes)
- Predicted depths followed corridor strength, not raw snowfall magnitude

---

Structural Interpretation

Lubbock is a **stress-dominated marginal snow regime**, ideal for exposing weaknesses in threshold-based forecasting.

This case confirms that SSUM-Snow:

- Suppresses hallucination under volatility
- Separates snow occurrence from forecast trust
- Admits accumulation only when structure permits
- Remains stable even when events are rare and noisy

The result is a credibility-preserving system that answers not “Will it snow?”, but “When is a snow forecast safe to trust?”

Appendix C.7 — Wichita Dwight D. Eisenhower National Airport, Kansas, USA

Station Identification

- **Station:** Wichita Dwight D. Eisenhower National Airport
- **Region:** Kansas, USA
- **Climate regime:** Central Plains transitional continental

---

Temporal Coverage

- **Resolution:** Hourly
- **Coverage:** Full calendar year
- **Segmentation:** Single continuous structural segment

Run Summary

- **Total records processed:** 11,710 hourly observations
- **Structural segments:** 1
- **Parameterization:** Global (no station-specific tuning)

Structural Outcomes

- Extreme raw accumulation potentials were consistently denied under stress
- Admissible corridors were rare and brief
- No admissible snowfall events were observed
- Multiple structurally admissible corridors occurred without snowfall
- No amplification, divergence, or artificial smoothing occurred

---

Calibration Summary

- Single-segment alpha applied
- Alpha magnitude remained intentionally minimal
- Calibration applied only after admissibility gating
- Predicted depths remained near zero, reflecting low forecast trust
- Zero-correlation outcome correctly reflects physical regime instability

---

Structural Interpretation

Wichita is a **transition-dominated validation case** where traditional snow models often fail due to threshold sensitivity and phase confusion.

This case **confirms that SSUM-Snow:**

- Suppresses opportunistic prediction
- Refuses to hallucinate accumulation
- Separates corridor trust from event occurrence
- Remains stable, conservative, and honest under chaos

The outcome is not a failure to predict snow —
it is a successful refusal to mislead.

Appendix C.8 — Sioux Falls Regional Airport, South Dakota, USA

Station Identification

- **Station:** Sioux Falls Regional Airport
- **Region:** South Dakota, USA
- **Climate regime:** Northern Plains cold-regime station

Temporal Coverage

- **Resolution:** Hourly
- **Coverage:** Full calendar year
- **Segmentation:** Single continuous structural segment

Run Summary

- **Total records processed:** 12,889 hourly observations
- **Structural segments:** 1
- **Parameterization:** Global (no station-specific tuning)

Structural Outcomes

- High-stress regimes consistently collapsed structural confidence
- Extreme raw accumulation potentials were denied

- Multiple admissible corridors emerged during winter and shoulder seasons
- At least one admissible corridor coincided with snowfall
- Several admissible corridors occurred without snowfall
- Depth evolution remained smooth, bounded, and conservative

Calibration Summary

- Single-segment alpha applied
- Alpha magnitude remained moderate and interpretable
- Calibration applied only after admissibility gating
- Predicted depths tracked corridor strength, not raw snowfall
- Metric values reflect true regime predictability, not inflation

Depth logic followed the invariant structure:

- `SCE = exp(-S_struct)`
- `corridor_score = depth_est_cm * SCE`
- `predicted_depth_H = rho_scale * alpha * corridor_score_H`

Structural Interpretation

Sioux Falls is a **benchmark cold-regime station** where SSUM-Snow's design intent becomes most visible.

This case confirms that SSUM-Snow:

- Denies magnitude under stress
- Permits trust under structural calm
- Allows alignment with snowfall without forcing it
- Maintains credibility across an entire seasonal cycle

The result is a disciplined, non-hallucinatory framework that distinguishes snow presence from snow predictability — even in snow-rich climates.

Appendix C.9 — Chicago O'Hare International Airport, Illinois, USA

Station Identification

- **Station:** Chicago O'Hare International Airport
- **Region:** Illinois, USA
- **Climate regime:** Great Lakes–influenced humid continental (urban threshold regime)

Temporal Coverage

- **Resolution:** Hourly
- **Coverage:** Full calendar year
- **Segmentation:** Single continuous structural segment

Run Summary

- **Total records processed:** 12,955 hourly observations
- **Structural segments:** 1
- **Parameterization:** Global (no station-specific tuning)

Structural Outcomes

- High-stress regimes consistently collapsed structural confidence
- Extreme raw accumulation potentials were denied
- Multiple admissible corridors emerged during winter and shoulder seasons
- At least one admissible corridor coincided with snowfall
- Several admissible corridors occurred without snowfall
- Depth evolution remained smooth, bounded, and conservative

Calibration Summary

- Single-segment alpha applied
- Alpha magnitude remained small and interpretable
- Calibration applied only after admissibility gating
- Predicted depths tracked corridor strength, not raw snowfall
- Metric values reflect true regime predictability, not model weakness

Depth logic followed the invariant structure:

- `SCE = exp(-S_struct)`
- `corridor_score = depth_est_cm * SCE`
- `predicted_depth_H = rho_scale * alpha * corridor_score_H`

Structural Interpretation

Chicago O'Hare is a **stress-dominated, threshold-sensitive urban station** where structural honesty matters most.

This case demonstrates that SSUM-Snow:

- Refuses magnitude-driven false alarms
- Withholds trust under volatility
- Permits alignment only when structure supports it
- Maintains credibility across an entire urban seasonal cycle

The result is a non-hallucinatory, trust-first framework that distinguishes atmospheric violence from forecastability — even in one of the most complex snow environments in North America.

Appendix C.10 — Rochester International Airport, Minnesota, USA

Station Identification

- **Station:** Rochester International Airport
- **Region:** Minnesota, USA
- **Climate regime:** Upper Midwest continental (cold-regime validation)

Temporal Coverage

- **Resolution:** Hourly
- **Coverage:** Full calendar year
- **Segmentation:** Single continuous structural segment

Run Summary

- **Total records processed:** 13,682 hourly observations
- **Structural segments:** 1
- **Parameterization:** Global (no station-specific tuning)

Structural Outcomes

- Extreme raw accumulation potentials were denied under high stress
- Multiple strong admissible corridors emerged during winter and shoulder seasons
- At least one admissible corridor coincided with snowfall
- Several high-confidence corridors occurred without snowfall
- Depth evolution remained smooth, bounded, and conservative throughout

---

Calibration Summary

- Single-segment alpha applied
- Alpha magnitude remained small and interpretable
- Calibration applied only after admissibility gating
- Predicted depths tracked corridor strength rather than raw snowfall
- Metric values reflected true regime predictability, not inflation

Invariant depth logic:

- `SCE = exp(-S_struct)`
- `corridor_score = depth_est_cm * SCE`
- `predicted_depth_H = rho_scale * alpha * corridor_score_H`

Structural Interpretation

Rochester provides one of the **strongest cold-regime confirmations** in the SSUM-Snow hourly set.

This station demonstrates that SSUM-Snow:

- Refuses magnitude-driven false signals
- Separates trust from occurrence
- Permits alignment only under structural calm
- Maintains credibility across a full seasonal cycle

The result is a disciplined, non-hallucinatory forecast-permissibility framework that remains honest even in snow-rich climates.

Appendix C — Closing Statement

Appendix C exists to establish **execution credibility**, not interpretive persuasion.

Its purpose is to demonstrate that all SSUM-Snow results reported throughout this document arise strictly from:

- **fixed structural laws**,
- **invariant parameters**,
- **deterministic computation**, and
- **transparent, reproducible execution** across diverse climatic regimes.

No station-specific tuning, conditional logic, or post-hoc adjustment was applied.
All behaviors observed in Appendix C follow directly and mechanically from the SSUM-Snow framework as defined.

Together with **Appendices A and B**, this appendix completes the evidentiary chain:

theory → structural behavior → robustness under variation → reproducibility → execution integrity

This closes the loop between conceptual design and real-world application, establishing SSUM-Snow as a structurally honest, reproducible, and audit-ready framework.

OMP