ORACLE V6.3 'SUSTAIN' Post-Mortem Analysis

Divergence of Simulated Thermodynamics and Historical Intensity in Hurricane Hugo (1989)

ORACLE Research Team

January 19, 2026

1 Executive Summary

This document constitutes a comprehensive, expert-level post-mortem analysis of the **ORACLE V6.3 'SUSTAIN'** simulation run, specifically targeting the reconstruction of the lifecycle of Hurricane Hugo (1989). The primary objective of this experimental iteration was to validate the "Intensity Maintenance Fix," a suite of algorithmic patches designed to address the systemic issue of premature intensity decay observed in previous V6.x iterations of the ORACLE kernel. Specifically, the simulation sought to test the hypothesis that a localized **WISHE (Wind-Induced Surface Heat Exchange) Boost**, combined with relaxed thermodynamic stability bounds and a "pure physics" configuration, would sustain the vortex intensity after its initial peak, thereby preventing the characteristic "spindown" that has historically plagued the V50.x tracking kernels in high-shear environments.

The simulation was executed with a rigorous set of parameters: a resolution boost reduced to 600 to mitigate effective viscosity, the complete deactivation of **Thermo Firewalls** to allow for extreme gradients, and a core relative humidity initialization of 85% to maximize the air-sea thermodynamic disequilibrium. The temporal domain spanned 50,000 frames, utilizing ERA5 historical steering data and a V5 Static North Atlantic Basin environment.

Critical Finding: The simulation failed to reproduce the historical intensity profile of Hurricane Hugo, invalidating the core hypothesis of the V6.3 patch set. While Hurricane Hugo historically achieved Category 5 status with sustained winds of 140–160 knots (kts) and a minimum central pressure of 918 mb [1, 2], the ORACLE V6.3 simulation achieved a peak intensity of only **67.0 kts** (Category 1) at Frame 200 before entering a definitive and unrecoverable decay phase. The system stabilized at a terminal intensity of approximately 30.8 kts, representing a gross underestimation of the storm's energetic potential.

The hypothesis that the **WISHE Boost (Max 2.0x)** would sustain intensity was largely invalidated by the operational telemetry. Despite the mechanism being explicitly enabled in the command line arguments (`--wishe-boost --wishe-boost-max 2.0`), the diagnostic logs indicate that the system struggled to maintain the necessary thermodynamic disequilibrium required for the feedback loop to latch. The maximum recorded boost was **1.00x** at Frame 0, reaching only **1.07x** by Frame 500.[3] This suggests that the interaction between the active **Flux Governor**, **Velocity Governor**, and the newly implemented **Cold Diffusion** algorithm created a "dampening trap." In this state, the artificial stability measures suppressed the explosive deep convection required for Rapid Intensification (RI) and the maintenance of a major hurricane vortex, effectively choking the storm's thermodynamic engine.

This report dissects the kinematic and thermodynamic evolution of the simulated storm, provides a forensic analysis of the failure modes associated with the V6.3 patches, and offers a comparative analysis against the historical meteorological record of Hurricane Hugo. The insights derived herein are intended to inform the architectural requirements for the V7.0 development cycle, specifically regarding the parameterization of boundary layer fluxes and the implementation of dynamic governors.

2 Theoretical Framework and Experimental Design

The V6.3 'SUSTAIN' configuration represented a significant and aggressive departure from standard operating parameters. It was engineered to target three specific inhibitors identified in previous post-mortems: Turbulence (excessive dissipation), Stratification (buoyancy inhibition), and Moisture (premature saturation). The experimental design relied on the premise that by uncapping physical limits, the natural non-linear instability of the tropical atmosphere would drive the storm to its potential intensity (PI).

2.1 The V6.3 Patch Architecture

The configuration flags passed to the solver (`--pure-physics --resolution-boost 600 --no-thermo-firewall --theta-prime-min -75 --theta-prime-max 75 --moist-floor 0.0 --updraft-only-moist --core-rh-in 0.85 --wishe-boost --wishe-boost-max 2.0 --cold-diffusion`) describe a model attempting to maximize energetic efficiency. The following analysis details the intended physical effect of each parameter versus its observed outcome.

2.1.1 Resolution and Turbulence Control

The **Resolution Boost** was set to **600**, a significant reduction from the default value of 1500. In the context of the ORACLE solver, this parameter likely controls the effective Reynolds number or the coefficient of eddy viscosity used in the sub-grid scale turbulence closure.[3]

- **Theory:** High viscosity (default 1500) creates a "Molasses Atmosphere," where turbulent mixing dissipates kinetic energy too rapidly, preventing the formation of tight, high-vorticity structures like the eye wall. Lowering this to 600 was intended to reduce this damping, allowing for sharper gradients and stronger peak winds.
- **Reality:** While this likely allowed for the initial rapid spin-up to 67 kts, it also likely made the grid more susceptible to numerical noise. The interaction between low viscosity and the "Cold Diffusion" patch suggests that the simulation traded viscous damping for diffusive smoothing, merely shifting the mechanism of energy loss rather than eliminating it.

2.1.2 Stratification and the "Buoyancy Tax"

The **Moist Floor** was set to **0.00** (default 0.3), and **Updraft-Only Moist** stratification was enabled.[3]

- **Theory:** In many non-hydrostatic models, the stratification term acts as a restoring force (a "tax") on rising air parcels. By forcing the moist floor to 0.0, the model essentially allows air parcels to rise with zero inhibition from static stability, provided they are buoyant. This removes the "Convective Inhibition" (CIN) barrier that often stifles weak storms.
- **Reality:** The logs show stratification efficiency (`eff`) remaining near 1.00 (100% efficiency) throughout the genesis phase. However, the storm still decayed. This leads to a critical insight: **The failure was not due to the *cost* of lifting air (which was zero), but due to the lack of *energy* (buoyancy) to lift it.** The engine had no friction, but it ran out of fuel.

2.1.3 Moisture and the WISHE Gradient

The **Core Relative Humidity (RH) Initialization** was lowered to **85%** from the default 95%.

- **Theory:** The WISHE (Wind-Induced Surface Heat Exchange) mechanism relies on the disequilibrium between the saturated sea surface (q^*_{sfc}) and the overlying boundary layer air (q_{air}). The flux of enthalpy (k) is proportional to $|V|(k^*_{sfc} - k_{air})$. By lowering the initial core humidity, the term $(k^*_{sfc} - k_{air})$ increases, theoretically boosting the flux of latent heat into the system.[4, 5]

- **Reality:** This parameter created a "Moisture Deficit" of **14.92 g/kg** at Frame 0.[3] While this maximized potential flux, it introduced a vulnerability. Deep convection requires the column to be nearly saturated to protect updrafts from the effects of dry air entrainment.[6, 7] By starting dry, the core was susceptible to dilution. The updrafts, though potentially energetic, likely lost buoyancy due to mixing with the sub-saturated core air before they could reach the tropopause and lower the surface pressure. This is a classic "Goldilocks" failure: the air was too dry to sustain the hot towers needed to spin up the vortex.

2.2 Active Governors and Constraints

A defining contradiction of the V6.3 simulation was the simultaneous operation of "Pure Physics" parameters alongside active stabilization governors. The logs explicitly state the status of these mechanical controllers:

- **Flux Governor: Active**
- **WISDOM Dampening: Active**
- **Velocity Governor: Active**
- **Thermo Firewalls: DISABLED**

The **Flux Governor** is particularly significant. In numerical weather prediction (NWP) and computational fluid dynamics, governors or limiters are often employed to prevent "numerical explosions" where fluxes exceed physical possibilities within a single time step.[8, 9] However, in the context of a hurricane simulation attempting to reproduce Category 5 intensity, these governors can act as an artificial ceiling. If the WISHE Boost commanded a 2.0x increase in enthalpy flux to simulate spray dynamics or high-wind coefficients, and the Flux Governor identified this as a violation of stability criteria (e.g., Courant numbers), it would clamp the flux back down. This effectively nullified the "Sustain" patch, trapping the simulation in a stable but low-intensity equilibrium.

3 Kinematic and Thermodynamic Evolution

The 50,000-frame simulation trajectory can be segmented into three distinct phases: The Genesis Sprint, The Peak & Rejection, and The Terminal Decay.

3.1 Phase 1: The Genesis Sprint (Frames 0 – 200)

The simulation initialized with a pre-balanced warm-core vortex characterized by a maximum potential temperature anomaly (θ'_{max}) of 4.99 K and an initial maximum wind (V_{max}) of 47.8 kts.

- **Frame 0 (Genesis):** The system successfully initialized the "WISHE Fuel" deficit ($q_{deficit}$) at **14.92 g/kg**.[3] This value, derived from a saturation humidity (q_{sat}) of 24.2 g/kg and a surface humidity (q_{sfc}) of 9.3 g/kg, represented a massive potential energy reservoir. The WISHE Boost was active but nominal (1.00x).
- **Frame 100 (Intensification):** The storm responded to the initial disequilibrium, intensifying to **62.3 kts**. The θ'_{max} spiked to **22.05 K**, indicating the successful ignition of deep convection and the release of latent heat. The "Buoyancy" diagnostic showed a raw value of 0.9667 m/s^2 with **0.0% clamping**, proving that the "No Thermo Firewalls" flag was functioning—the physics engine allowed the updrafts to accelerate without artificial braking.
- **Frame 200 (The Peak):** The storm reached its absolute simulation zenith at **67.0 kts**, classified in the logs as a "V47 BULLSEYE" in the Hurricane phase. The updraft velocity peaked at **58.03 m/s**, and the core thermal anomaly reached **23.53 K**.

Insight: The rapid ascent from 47.8 kts to 67.0 kts within 200 frames confirms that the *potential* for intensification existed within the initial setup. The lowered RH successfully maximized the air-sea enthalpy disequilibrium. However, the peak of 67 kts represents a "glass ceiling"—barely scratching Category 1 intensity—whereas the historical Hugo was undergoing explosive deepening toward Category 3 and eventually Category 5 during this timeframe.[1]

3.2 Phase 2: Peak Rejection and Immediate Decay (Frames 200 – 500)

The critical failure of the simulation occurred immediately following Frame 200. Instead of sustaining the 67 kt intensity or utilizing the WISHE feedback loop to vault into major hurricane status, the vortex collapsed.

- **Frame 300:** Winds dropped to **59.6 kts**. θ'_{max} decreased to 19.56 K.
- **Frame 400:** Winds collapsed further to **46.9 kts** (reverting to Tropical Storm status). θ'_{max} fell to 15.33 K.
- **Frame 500:** A slight, non-sustaining recovery to **53.4 kts**, but the thermodynamic structure was fatally compromised. The log notes a core temperature (T_{core}) of -9.2°C and a θ'_{core} of only 3.60 K.[3]

Thermodynamic Disconnect: The log at Frame 500 reveals a critical structural failure. While the θ'_{max} in the domain was 27.50 K (likely in a localized, transient hot tower), the *core* θ' was only 3.60 K. This indicates a **decoupling of the warm core**. The convection was firing (Buoyancy Raw=0.8820), but it was not efficiently depositing heat into the eye/core region to lower the central pressure and drive the tangential wind field. This is a classic signature of **Ventilation** or **Shear-induced misalignment**, where the heat release is advected away from the dynamic center.[10] In this idealized run without strong environmental shear, it suggests an internal model failure to symmetrize the heating, likely due to the aggressive **Cold Diffusion** smoothing out the gradients necessary for axisymmetrization.

3.3 Phase 3: Terminal Decay and Oscillation (Frames 500 – 50,000)

Following the initial collapse, the simulation entered a state of damped oscillation, never recovering hurricane intensity.

- **Frames 600-1000:** Winds fluctuated between 32 kts and 48 kts. The system repeatedly transitioned between "Potential" (depression/wave) and "TS" (tropical storm) stages.
- **Long-term Trend:** The final summary indicates a trend of "Decaying" with a final intensity of **30.8 kts**.[3] This essentially represents a dissipated remnant low.

The Oscillation Phenomenon: The oscillating intensity observed (e.g., Frame 800: 32.6 kts → Frame 1000: 39.3 kts → Frame 1100: 31.8 kts) aligns with research findings on **CAPE-intensity interactions** in simulations where the WISHE mechanism is inefficient or suppressed.[5] When the WISHE feedback is weak, the cyclone consumes available Convective Available Potential Energy (CAPE), intensifies briefly, stabilizes the atmosphere (consuming the CAPE), decays, and then waits for radiative cooling or surface fluxes to restore instability. This "recharge-discharge" cycle confirms that the continuous, positive feedback loop of WISHE—where wind creates flux, which creates wind—was never successfully established.

4 Critical Failure Analysis: Why "SUSTAIN" Failed

The failure of the "SUSTAIN" fix to maintain intensity, despite explicit boosting parameters and relaxed bounds, points to fundamental conflicts between the physics implementation and the governor architecture.

4.1 The WISHE Boost Paradox

The most perplexing aspect of the logs is the **WISHE BOOST** metric.

- **Configuration:** The system was configured with `--wishe-boost` and `--wishe-boost-max 2.0`.
- **Observation:** Frame 0 reports `WISHE BOOST: max=1.00x`. Frame 500 reports `WISHE BOOST: max=1.07x`.[3]

Analysis: The system was authorized to double the enthalpy exchange coefficient (C_k), yet it barely applied a 7% boost even as the storm collapsed. The logic for the boost is tied to "high winds" to maintain a C_k/C_d ratio > 1.2.[11, 12]

- **Thresholding Issue:** Theoretical models typically require wind speeds to exceed a specific threshold (often $\sim$33 m/s or 64 kts) before the drag coefficient (C_d) increases sufficiently to degrade the C_k/C_d ratio, necessitating the boost.[13]
- **The Trap:** The simulation peaked at 67 kts (Frame 200). It is highly probable that the boost logic was triggered *at* the peak, but the **Velocity Governor** or **Flux Governor** prevented the wind speed from sustaining that threshold long enough for the boost to impact the thermodynamic cycle. The boost acts as a *reactive* measure in this code base; if the storm decays below the threshold (as it did by Frame 300, dropping to 59.6 kts), the boost deactivates (dropping back to $\sim$1.0x), ensuring the decay continues. This creates a feedback loop of failure: **Insufficient Wind → No Boost → Decay → Even Less Wind.**

4.2 The C_k/C_d Ratio and Physical Limits

The "SUSTAIN" fix attempts to enforce $C_k/C_d > 1.2$. In physical reality and advanced simulations, this ratio is effectively the "thermodynamic efficiency" of the hurricane engine.

- **Drag (C_d):** Increases with wind speed (rougher ocean, more wave breaking).
- **Enthalpy Transfer (C_k):** Must increase commensurately to fuel the storm.
- **The Conflict:** Standard bulk aerodynamic formulas often cap C_k or allow C_d to grow too large at high winds, causing the ratio to drop below 0.75-1.0, which stifles intensification.[12, 14]

The ORACLE simulation likely utilizes a parametrization where C_d scales aggressively with wind speed. By enabling the WISHE boost but keeping the **Flux Governor** active, the system likely identified the "boosted" fluxes as "unphysical" or "runaway" energy extraction. The Flux Governor [3, 8] acts as a limiter on the magnitude of energy transfer per time step. If the Boost algorithm requested a 2.0x flux multiplier, and the Governor clamped it to 1.1x (consistent with the observed 1.07x boost), the "Sustain" patch was effectively nullified by the safety protocols.

4.3 Governor Interference and Cold Diffusion

The **Cold Diffusion** patch (Strength 0.050) was introduced to smooth "cold holes" ($\theta' < -4K$) to prevent crashes.

- **Unintended Consequence:** While intended to stabilize the grid, diffusion is a dissipative process. In the logs, we see θ'_{core} values dropping significantly (e.g., 3.60 K at Frame 500) while localized maxima remain high.
- **Gradient Erosion:** Tropical cyclones run on gradients. By smoothing out cold anomalies, the diffusion algorithm likely also smoothed out the sharp gradients of moisture and temperature required for the **Vortical Hot Towers (VHTs)** to organize and merge.[15] VHTs rely on protecting their warm/moist cores from the surrounding drier environment. If the diffusion is too aggressive, it "dilutes" the hot towers with environmental air, reducing their buoyancy efficiency. This effectively simulates "Entrainment" [16], a known mechanism for weakening TCs.

The **Velocity Governor**, active throughout, likely capped the acceleration vectors. In the moments of Rapid Intensification (RI) between Frame 0 and 200, the acceleration was high. If the governor clamped the wind acceleration to prevent CFL violation, it artificially halted the spin-up process just as the WISHE feedback was attempting to engage.

5 Comparative Analysis: Simulation vs. Historical Reality

The divergence between the ORACLE V6.3 simulation and the historical reality of Hurricane Hugo is stark and instructive.

5.1 Historical Intensity Profile (Hugo 1989)

Parameter	**Historical Reality** [1, 2, 17, 18]	**ORACLE V6.3 Simulation**	**Variance**
Genesis Location	Off African Coast (Cape Verde)	13.2°N, 20.0°W (Correct)	N/A
Rapid Intensification	Sep 13-15: TS → Cat 5	Frame 0-200: TS → Cat 1	Failed Sustained RI
Peak Winds	**160 kts (185 mph)**	**67.0 kts**	**-58%**
Peak Pressure	**918 mb**	N/A (Pmin ∼ -0.00 anomaly)	N/A
Structure	Well-defined Eye, Symmetric	Asymmetric, Decoupled Core	Structural Failure
Decay Phase	Post-Landfall / Extratropical	Immediate Post-Peak	Premature
Landfall Intensity	Cat 4 (140 mph) in SC	Remnant Low (∼30 kts)	Catastrophic Miss

5.2 The "Missing" Physics

Historical analysis of Hugo highlights several factors that the "Pure Physics" V6.3 simulation, with its idealized environment, failed to capture:

1. **Ocean Heat Content (OHC) and Dynamic Coupling:** Hugo traversed regions of high Tropical Cyclone Heat Potential (TCHP). The simulation utilized a **V5 Static Basin**. Real-world TCHP allows for sustained deep convection even as the storm mixes the upper ocean layer.[19, 20] A static basin often lacks the "reservoir" effect; if the model calculates SST cooling (negative feedback), a static basin cannot replenish the heat from below, leading to rapid "self-induced" decay.[21]

2. **Barrier Layers:** Research indicates that salinity-induced barrier layers can prevent TC-induced cooling, potentially boosting intensification rates by 50%.[21] The V5 Basin description does not mention salinity profiles or barrier layer simulation, suggesting this positive feedback mechanism was absent.

3. **Environmental Moisture:** Hugo maintained intensity despite dry air (Saharan Air Layer - SAL) proximity because its inner core was robust and shielded. The simulation initialized with **85% Core RH** (reduced from 95%). While intended to increase the *flux gradient* (evaporation potential), this lower humidity likely made the vortex too susceptible to dry air entrainment.[6, 7] If the core is too dry, updrafts lose buoyancy due to entrainment dilution before they can reach the tropopause, preventing the pressure fall required to drive high winds.

6 Deep Dive: The Thermodynamics of Failure

The logs provide a forensic trail of the thermodynamic failure. We can reconstruct the energy cycle breakdown by analyzing the stratification and moisture variables.

6.1 Stratification and the "Buoyancy Tax"

The log shows `eff=1.00` and `eff_updraft=1.00` at Frame 0. By Frame 500, `eff=0.99` and `eff_updraft=0.98`.[3] The patch set `Moist Floor: 0.00` was intended to remove the "Buoyancy Tax." In many numerical models, stratification (stability) acts as a tax on rising parcels—they must do work against the stable environment to rise. By setting the floor to 0.0, the model essentially allows parcels to rise with zero inhibition.

Insight: The fact that the storm *still* decayed despite having "free" lift suggests that the **energy input** (Flux) was insufficient, not that the **energy cost** (Stratification) was too high. The engine had no friction (thermodynamically), but it ran out of fuel. The "Moist Floor" patch was a solution to a problem that didn't exist in this specific run.

6.2 The Moisture Deficit Miscalculation

The decision to lower `Core RH Init` to 85% was based on the standard bulk aerodynamic premise that Flux $\propto |V|(q^*_{sfc} - q_{air})$. By lowering q_{air}, the gradient $(q^*_{sfc} - q_{air})$ increases, theoretically boosting Flux.

However, this ignores the **Critical Relative Humidity** threshold for deep convection. Convection schemes often require a column to be nearly saturated (often ¿80–90% through a deep layer) to sustain the deep, undiluted updrafts that stretch vorticity.[15] By drying the core to 85%, the simulation likely forced the initial convection to be "diluted" (entraining dry air), which reduces the realized buoyancy.

- **Trade-off:** The configuration increased the *potential* evaporation rate, but decreased the *efficiency* of converting that moisture into kinetic energy via latent heat release. The "Moisture Deficit" of 14.92 g/kg [3] was high, but the storm couldn't utilize it fast enough before the dynamics decoupled. The atmosphere was thirsty, but the engine couldn't drink fast enough.

6.3 The Cold Diffusion Damping

The log notes: `COLD DIFFUSION: 0 cells smoothed` at Frame 0, Frame 100, etc..[3] This reporting might be misleading. If the diffusion algorithm is running as a background smoothing process (Strength 0.050), it may be subtly eroding gradients without triggering the "smoothed cell" counter (which might only count extreme outliers). In a simulation with a resolution boost (600), grid-scale noise is common. If the diffusion is applied globally or aggressively, it acts as an artificial viscosity. This would explain why the core thermal anomaly (θ'_{core}) dropped so precipitously (from ∼23K to ∼3K) between frames 200 and 500. The heat was diffused out of the core, flattening the pressure gradient and spinning down the wind field.

7 Recommendations for V7.0 Architecture

The failure of V6.3 'SUSTAIN' demonstrates that piecemeal "patches" (e.g., forcing a boost, relaxing a bound) cannot overcome fundamental deficits in the coupled air-sea-physics model. The following architectural changes are recommended for the V7.0 iteration to accurately capture Category 5 dynamics:

7.1 Dynamic Flux Governance

The static **Flux Governor** must be replaced with a **Dynamic WISHE Governor**.

- **Current:** Clamps fluxes based on absolute limits or simple smoothing, likely interpreting Cat 5 fluxes as errors.

- **Proposed:** A governor that specifically enforces the C_k/C_d ratio based on the local Rossby number or Inertial Stability. If the vortex is contracting and spinning up ($Ro > 10$), the governor should *relax* flux limits to allow the super-gradient winds observed in reality.[13] The WISHE boost should be intrinsic to the flux parameterization (a variable coefficient) rather than a post-hoc multiplier.

7.2 Ocean Mixed Layer (OML) Coupling

The **V5 Static Basin** is obsolete for simulating major hurricanes like Hugo.

- **Proposed:** Implement a 1.5-layer Reduced Gravity Ocean model or a Slab Ocean model with variable **Tropical Cyclone Heat Potential (TCHP)**. This will allow the simulation to account for the "Cooling Wake" effect.[21, 22] Crucially, it must model the *resistance* to cooling provided by deep warm layers (Barrier Layers), which likely fueled Hugo's Cat 5 run.

7.3 Moisture Initialization Strategy

The 85% RH initialization was a strategic error.

- **Proposed:** Return to **95%+ Inner Core RH**, but introduce a sharp radial gradient to drier environmental air. This mimics the "Moist Envelope" protecting the core.[7] To drive fluxes, focus on the **Sea Surface Temperature (SST)** disequilibrium rather than drying the air. Increasing the SST under the eyewall (representing a warm eddy) is a more physical way to boost flux than artificially drying the boundary layer.

7.4 Cold Diffusion Refinement

The **Cold Diffusion** (0.050) is likely too aggressive and unselective.

- **Proposed:** Implement **Selective Diffusion** or high-order filtering. Diffusion should only apply to grid cells exhibiting non-physical gradients (numerical noise), not to the structural cold pools associated with mesovortices. Over-diffusion kills the "battery" of the storm.

7.5 Resolution and VHT Resolution

The boost to **600** was a step in the right direction, but likely insufficient to resolve the **Vortical Hot Towers (VHTs)** that drive intensification.

- **Proposed:** If the grid cannot resolve 1-5km scales explicitly, the model must use a **VHT Parameterization** that injects vorticity into the boundary layer in response to CAPE consumption, rather than relying on bulk updrafts.[15, 23]

8 Conclusion

The ORACLE V6.3 simulation of Hurricane Hugo successfully initialized a tropical cyclone but failed to reproduce the rapid intensification and sustained intensity of the historical event. The diagnosis reveals that the **WISHE Boost** mechanism was effectively choked by a combination of the **Velocity Governor** and the thermodynamic inefficiency caused by a **low-humidity initialization**. The storm engine was starved of fuel (moisture efficiency) and throttled by its own safety mechanisms (governors), while the **Cold Diffusion** algorithm likely eroded the thermal gradients necessary to maintain the core.

For V7.0, the "Pure Physics" approach must be matched with "Pure Environment"—specifically, a dynamic ocean and a moisture profile that respects the necessity of saturation for deep convection. The "Sustain" patch proved that you cannot force a hurricane to maintain intensity simply by allowing it to break physical limits; the underlying energy cycle must be closed and efficient.

Final Status: Hypothesis Invalidated. The system requires architectural evolution of the Boundary Layer Flux parameterization and Governor logic before it can accurately hindcast Category 5 intensity maintenance. The use of ERA5 reanalysis data for initialization remains valid, but the internal handling of that data requires significant refinement to support the extreme physics of a major hurricane.