Scenario 1A: Assignment of Zero to Individual Inputs

Metamorphic Relation Type: Exclusive (E)

Description

In this scenario, the evaluator assesses the system’s sensitivity by assigning the value zero to exactly one abstract input variable at a time, while keeping all other inputs unchanged.

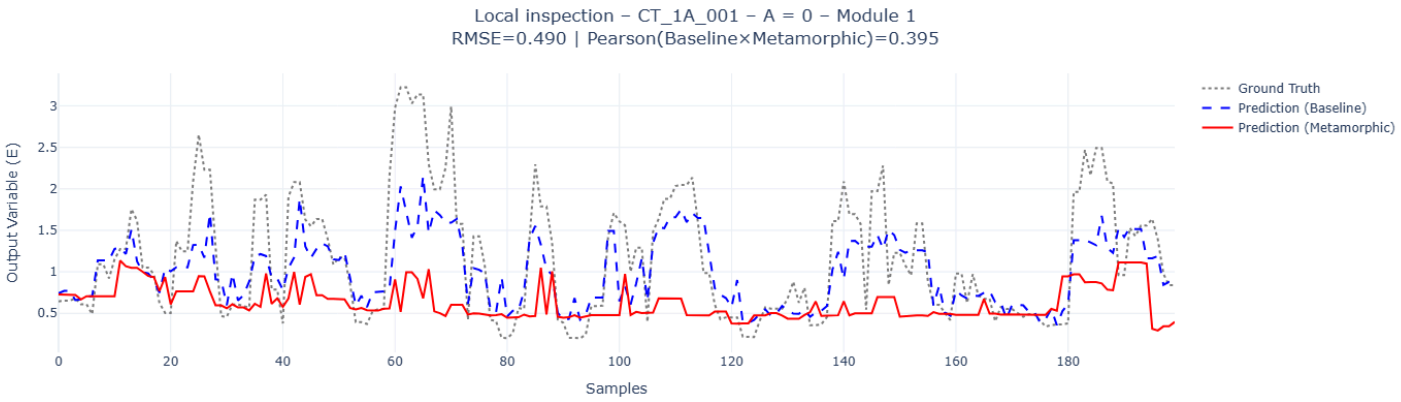
Each execution with modified data produces a Metamorphic Prediction, which is compared against the Baseline Prediction obtained from the unmodified reference dataset using quantitative metrics.

Assigning zero excludes the contribution of the selected input variable from the input vector. Observable deviations between the Baseline Prediction and the Metamorphic Prediction indicate that the excluded variable influences the system’s behavior under a strict black-box assumption.

Test Cases

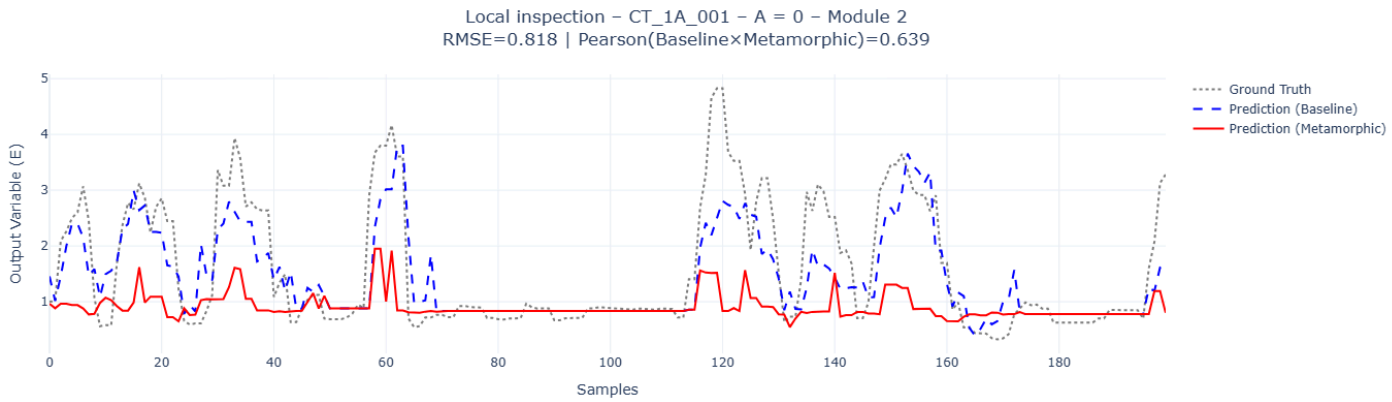
CT_1A_001 — Exclusive Relation (A = 0) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.4900
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.395
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.406



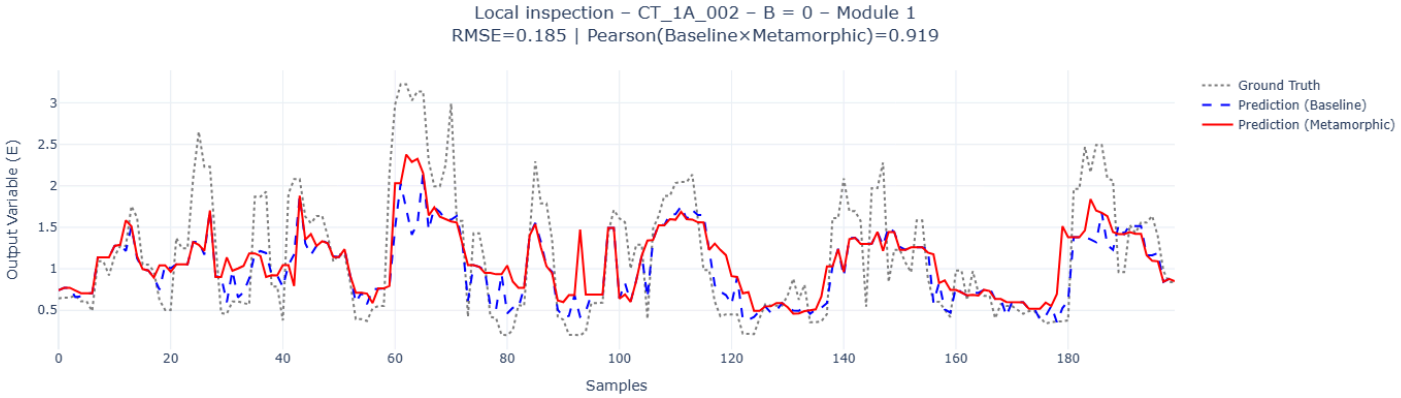
CT_1A_001 — Exclusive Relation (A = 0) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.8179
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.639
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.537



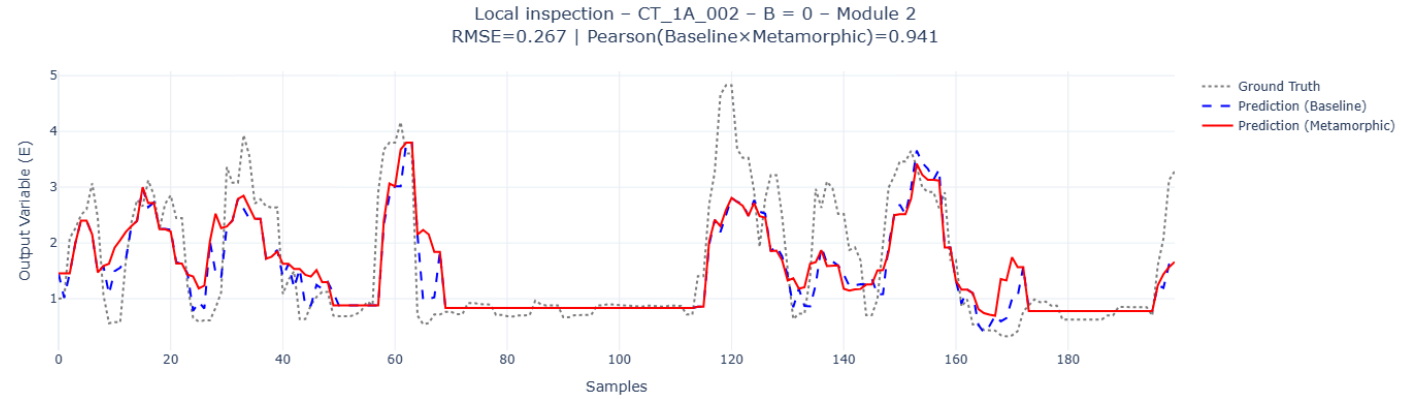
CT_1A_002 — Exclusive Relation (B = 0) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.1847
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.919
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.779



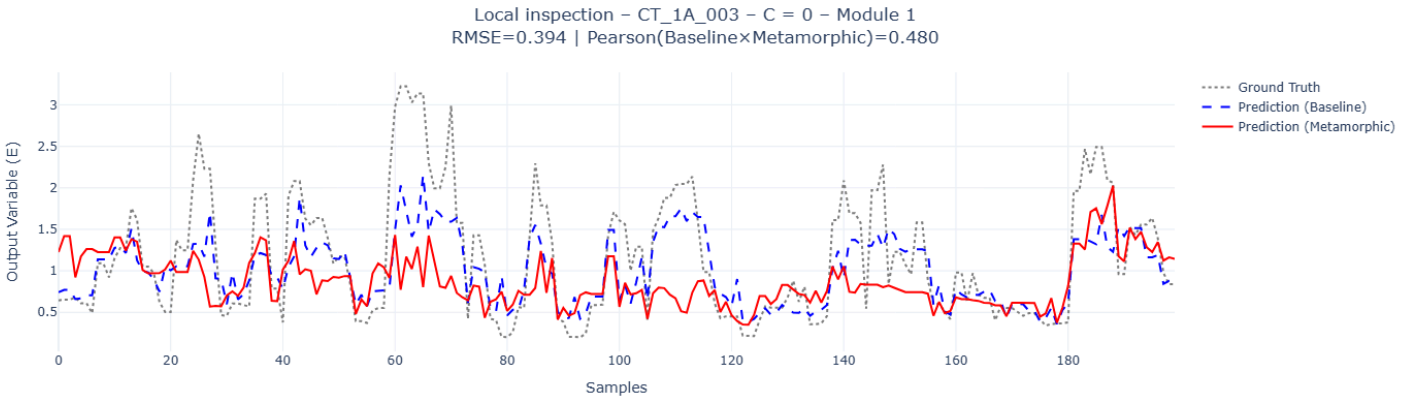
CT_1A_002 — Exclusive Relation (B = 0) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.2673
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.941
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.733



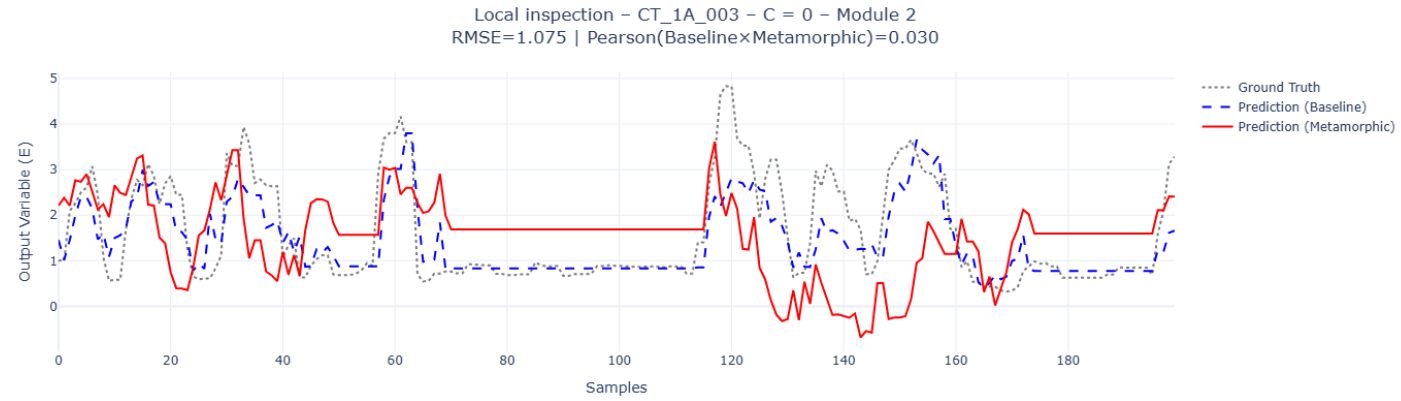
CT_1A_003 — Exclusive Relation (C = 0) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.3941
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.480
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.458



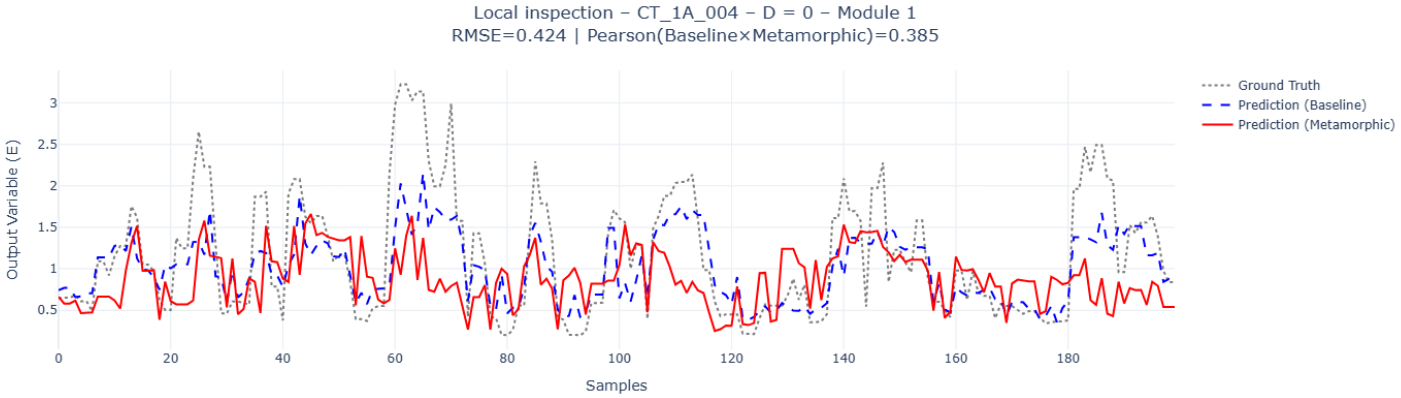
CT_1A_003 — Exclusive Relation (C = 0) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 1.0747
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.030
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.020



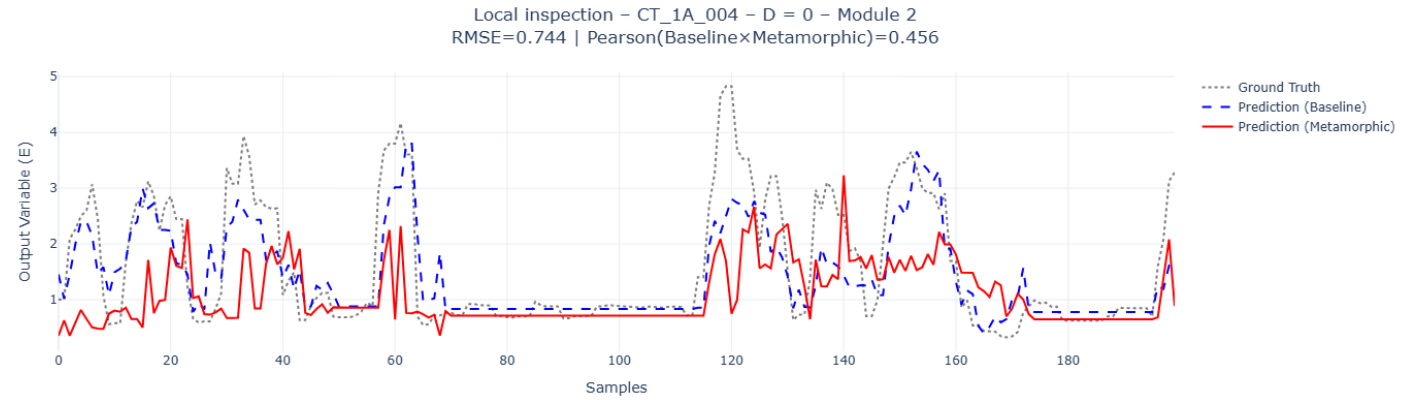
CT_1A_004 — Exclusive Relation (D = 0) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.4241
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.385
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.351



CT_1A_004 — Exclusive Relation (D = 0) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.7443
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.456
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.398



Scenario 1B: Assignment of NULL to Individual Inputs

Metamorphic Relation Type: Exclusive (E)

Description

This scenario evaluates the system’s behavior when NULL values are assigned individually to abstract input variables.

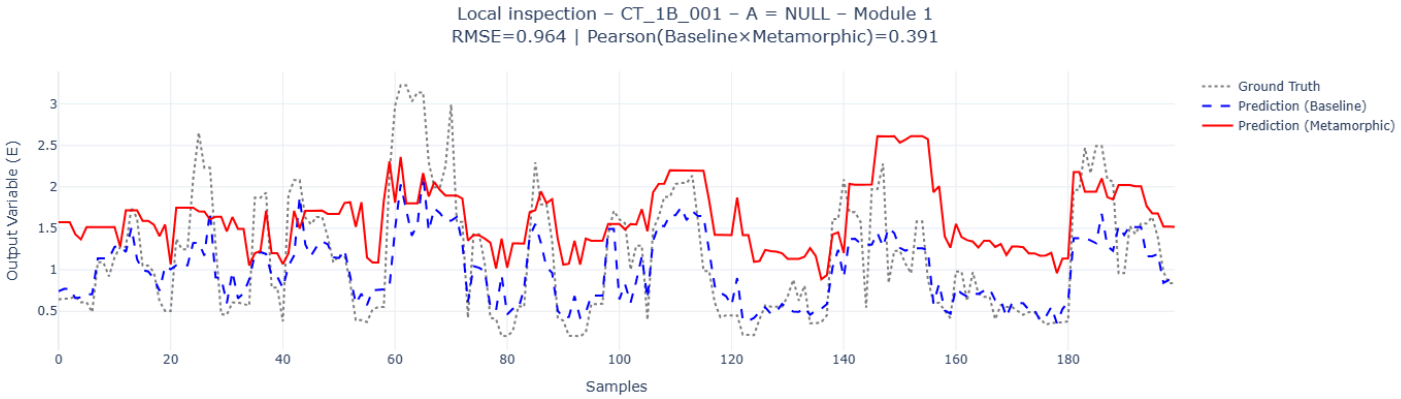
Each test case removes one input variable from effective participation in the computation by replacing its value with NULL, while all other inputs remain unchanged.

The evaluator observes whether the system output changes, becomes undefined, or whether the execution is interrupted, indicating that the excluded variable interferes with the system’s operation.

Test Cases

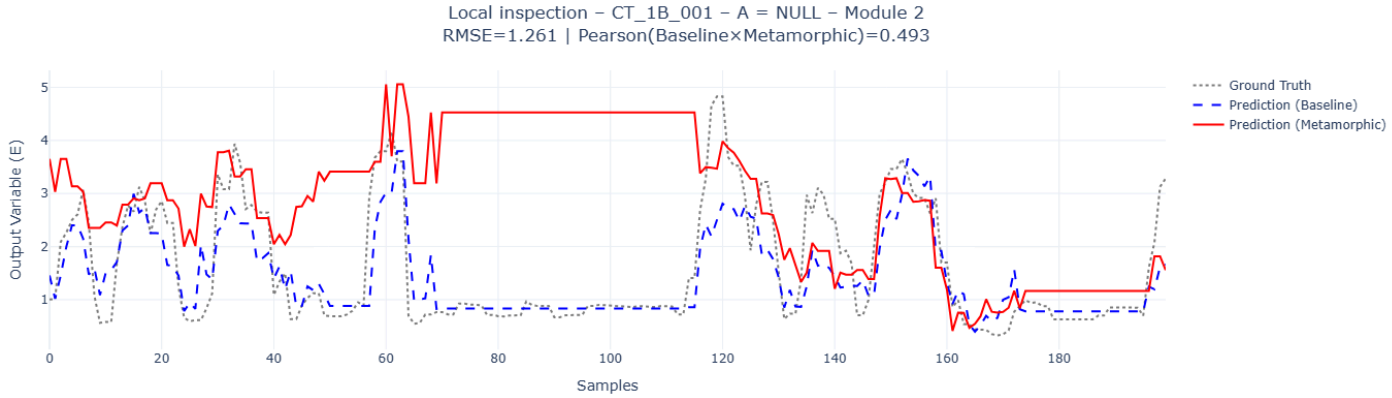
CT_1B_001 — Exclusive Relation (A = NULL) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.9639
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.391
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.347



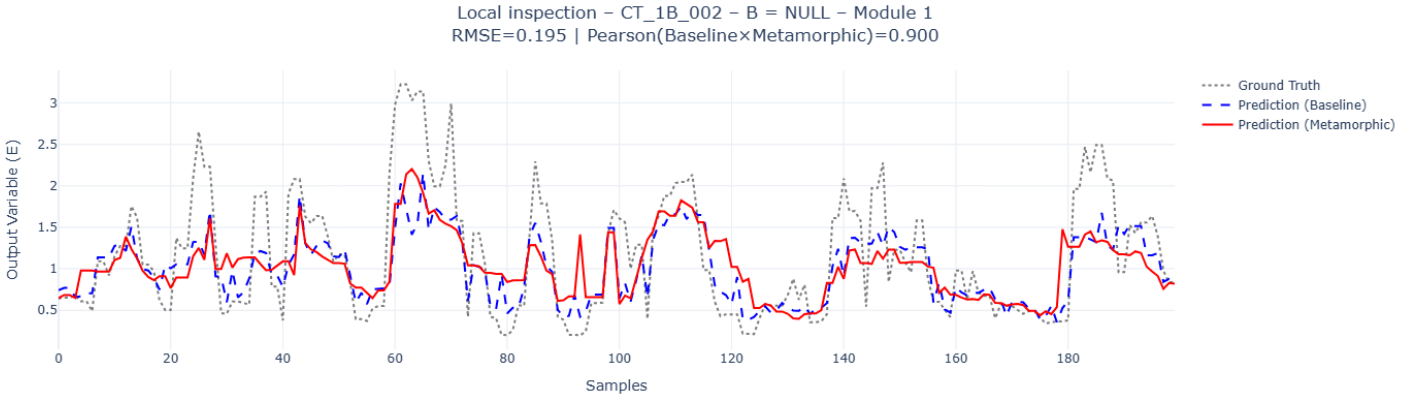
CT_1B_001 — Exclusive Relation (A = NULL) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 1.2611
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.493
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.391



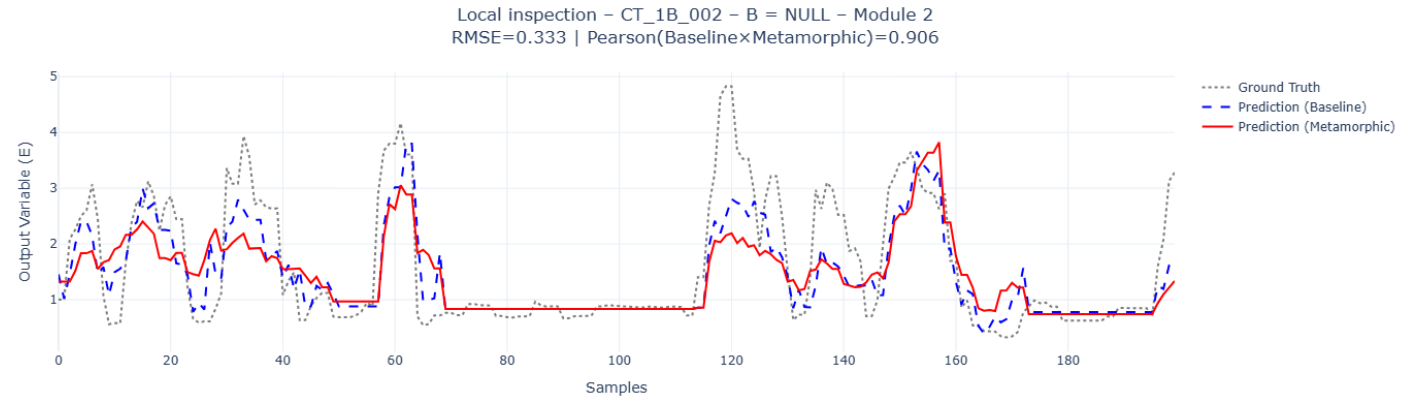
CT_1B_002 — Exclusive Relation (B = NULL) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.1949
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.900
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.752



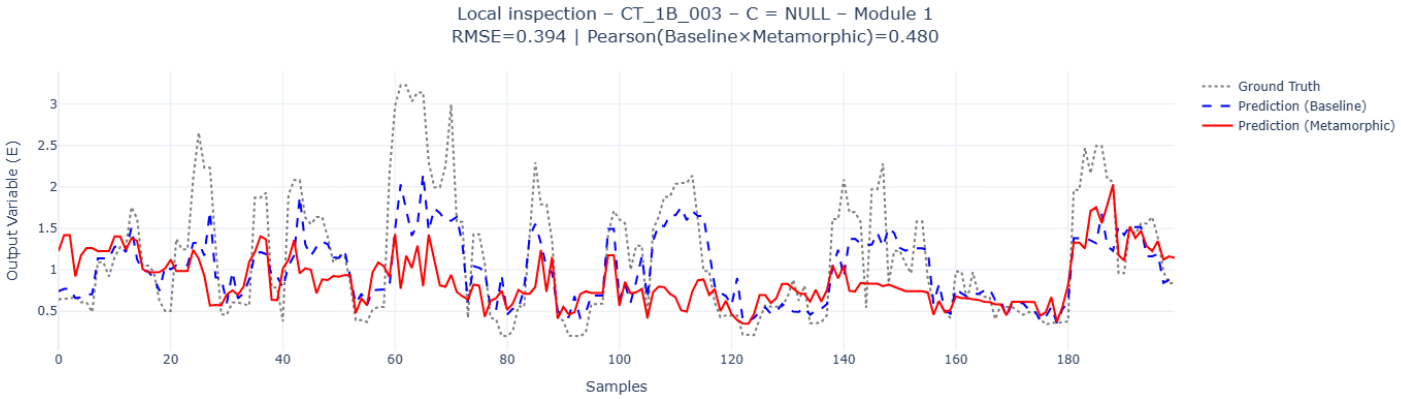
CT_1B_002 — Exclusive Relation (B = NULL) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.3328
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.906
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.712



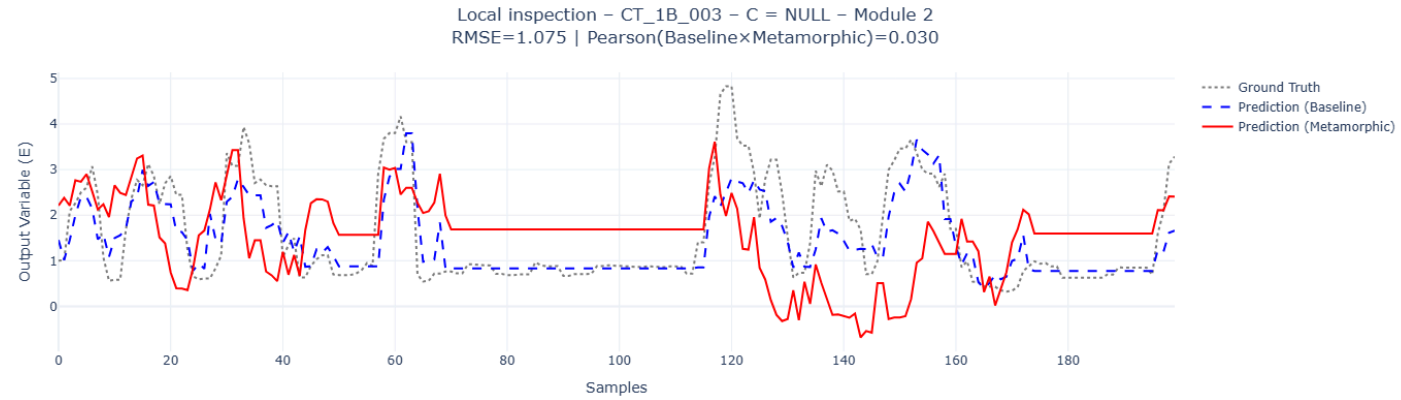
CT_1B_003 — Exclusive Relation (C = NULL) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.3941
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.480
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.458



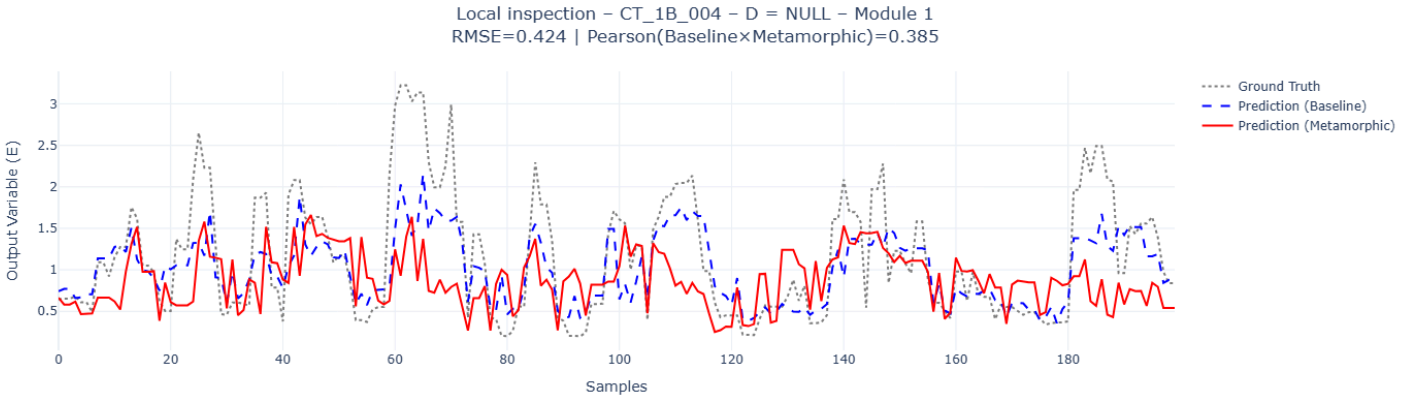
CT_1B_003 — Exclusive Relation (C = NULL) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 1.0747
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.030
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.020



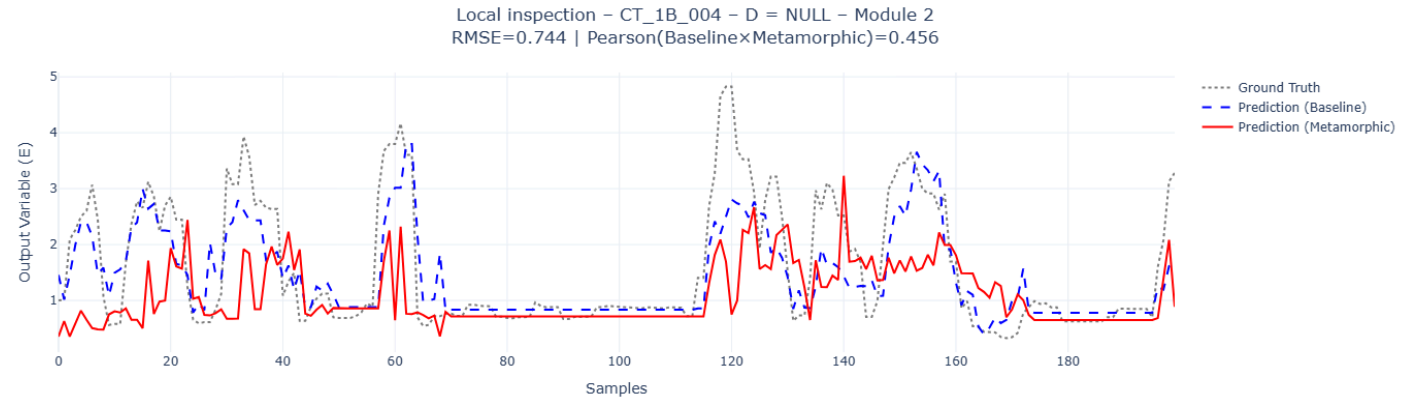
CT_1B_004 — Exclusive Relation (D = NULL) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.4241
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.385
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.351



CT_1B_004 — Exclusive Relation (D = NULL) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.7443
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.456
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.398



Scenario 1C: Temporal Lag Applied to Individual Inputs

Metamorphic Relation Type: Permutative (P)

Description

In this scenario, the evaluator investigates the effect of temporal reordering applied to individual abstract input variables.

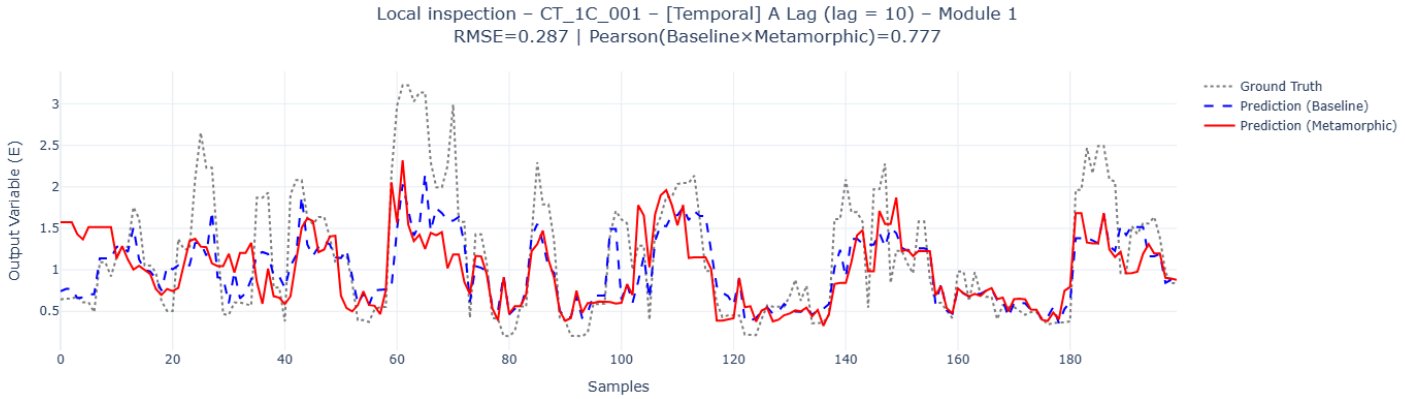
Each test case introduces a temporal lag of 10, 50, or 100 samples to one input variable, while preserving the original ordering of the remaining inputs.

The transformation alters the alignment of samples without modifying their individual values, allowing the evaluator to observe whether temporal displacement of a single variable interferes with the system’s output behavior or execution.

Test Cases

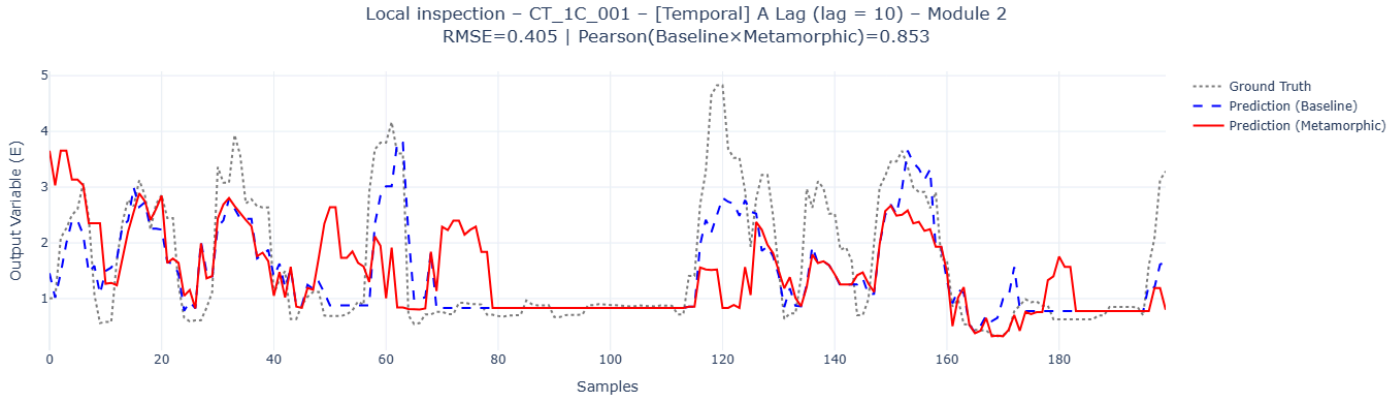
CT_1C_001 — Temporal Relation (A Lag = 10) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.2870
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.777
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.625



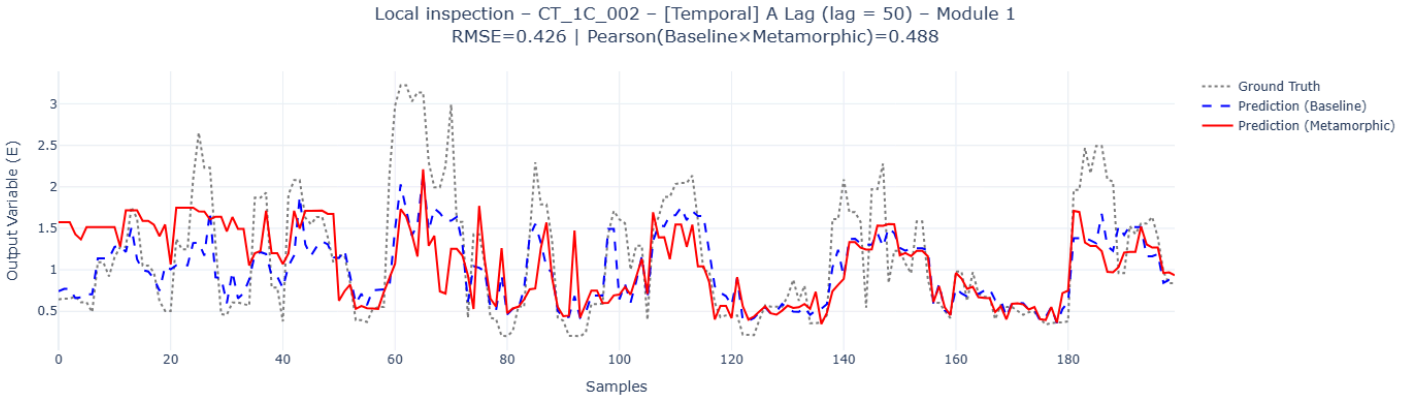
CT_1C_001 — Temporal Relation (A Lag = 10) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.4046
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.853
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.676



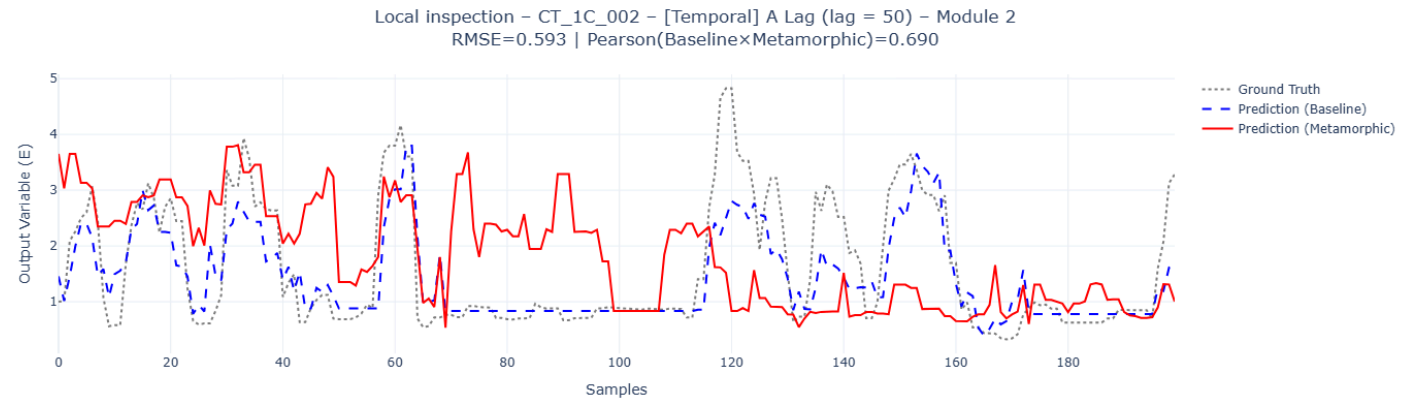
CT_1C_002 — Temporal Relation (A Lag = 50) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.4265
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.488
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.391



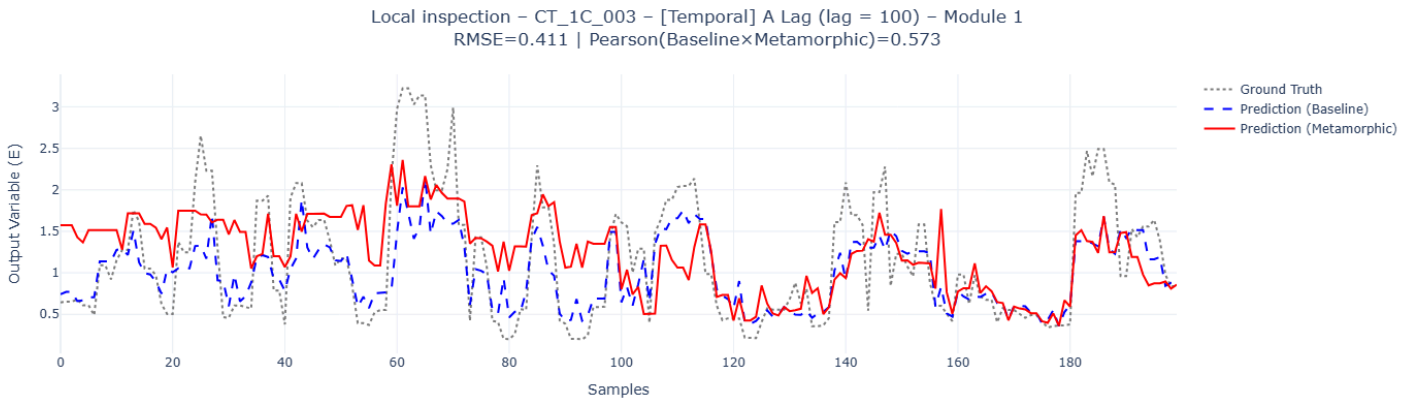
CT_1C_002 — Temporal Relation (A Lag = 50) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.5931
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.690
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.547



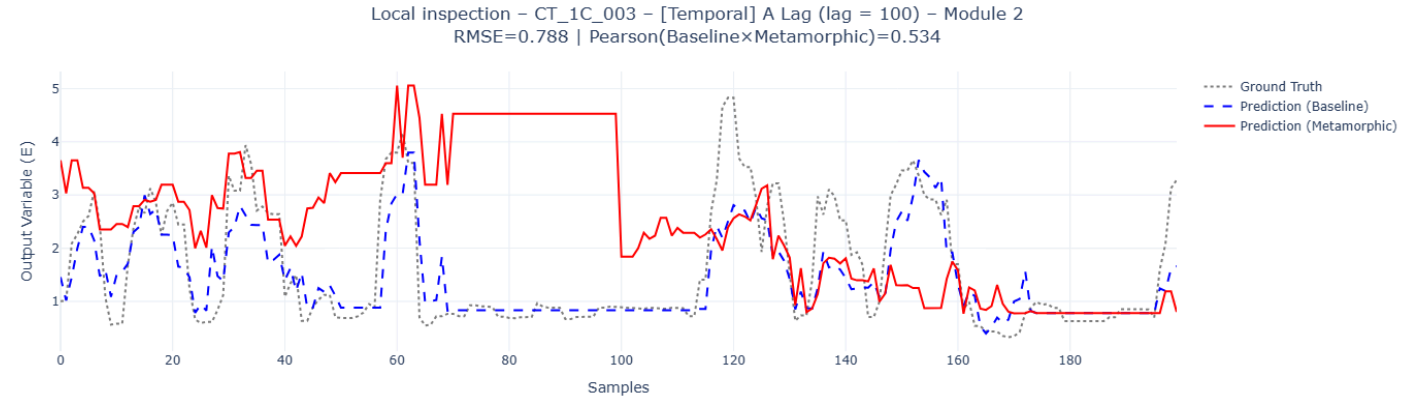
CT_1C_003 — Temporal Relation (A Lag = 100) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.4105
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.573
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.500



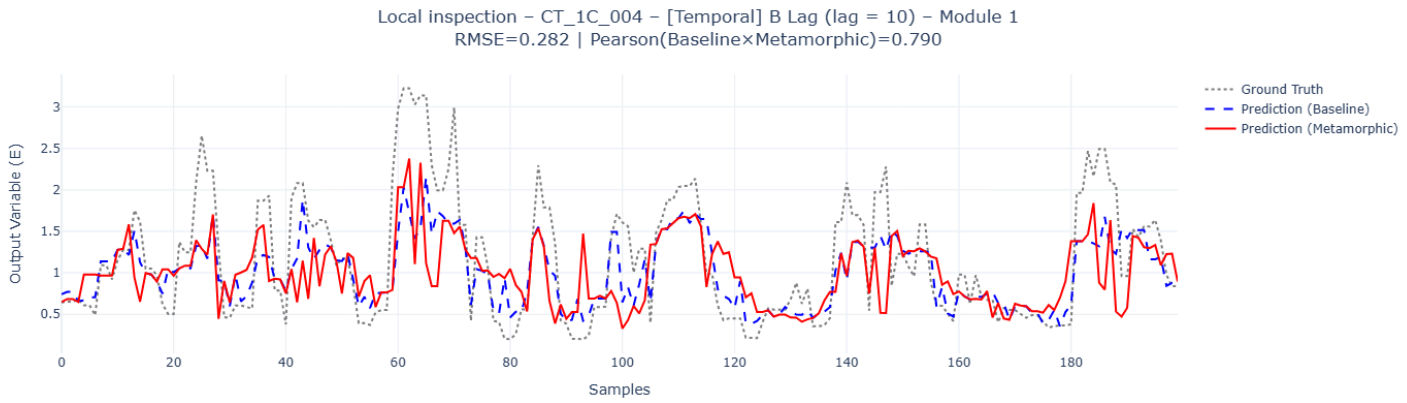
CT_1C_003 — Temporal Relation (A Lag = 100) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.7877
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.534
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.416



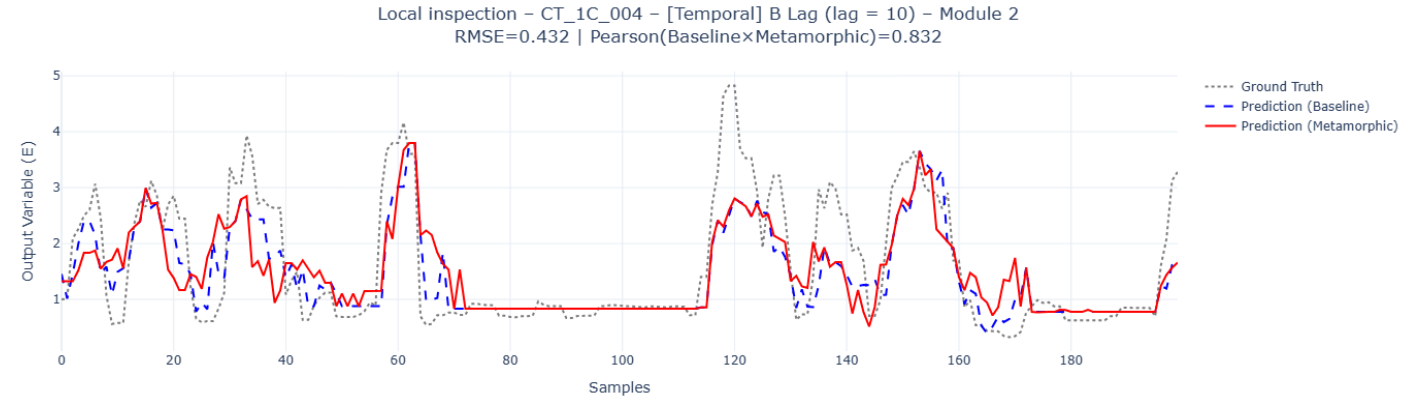
CT_1C_004 — Temporal Relation (B Lag = 10) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.2819
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.790
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.673



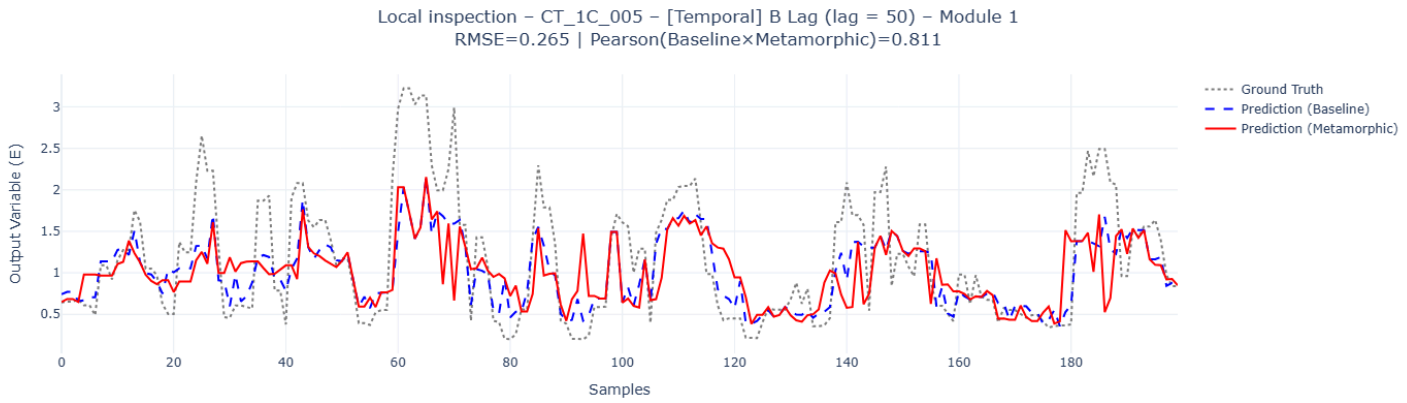
CT_1C_004 — Temporal Relation (B Lag = 10) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.4323
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.832
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.645



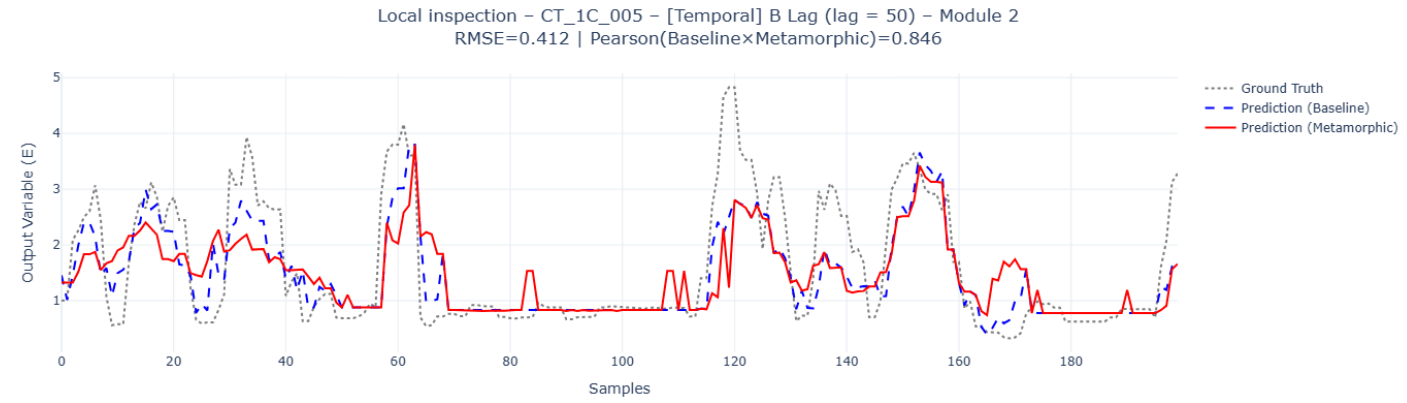
CT_1C_005 — Temporal Relation (B Lag = 50) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.2651
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.811
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.681



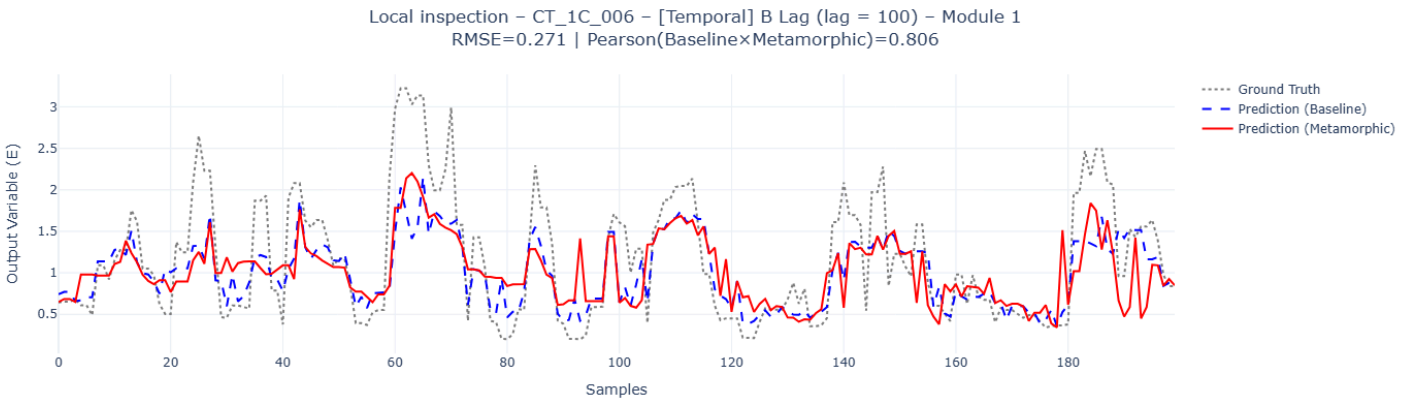
CT_1C_005 — Temporal Relation (B Lag = 50) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.4118
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.846
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.666



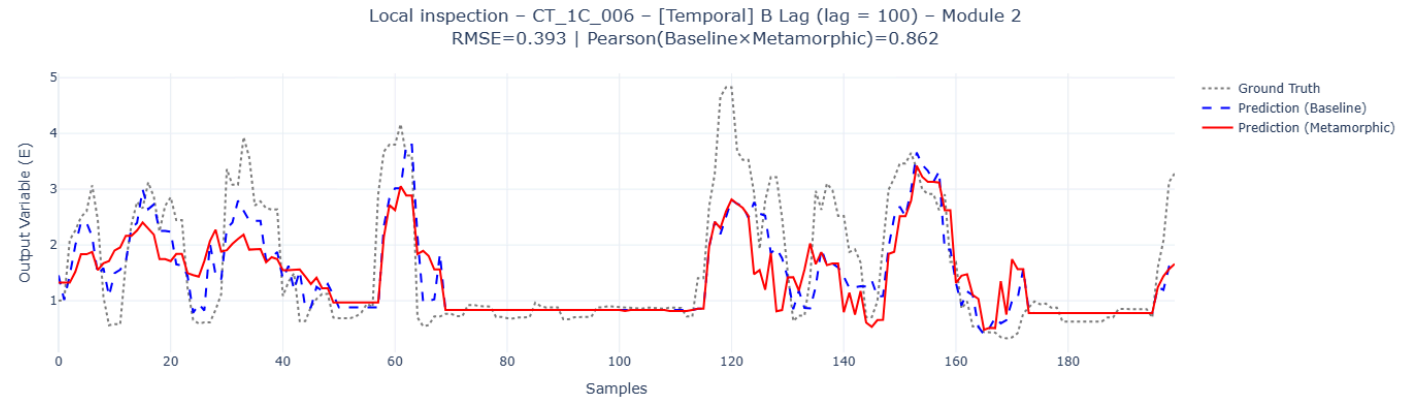
CT_1C_006 — Temporal Relation (B Lag = 100) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.2710
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.806
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.692



CT_1C_006 — Temporal Relation (B Lag = 100) — Module 2

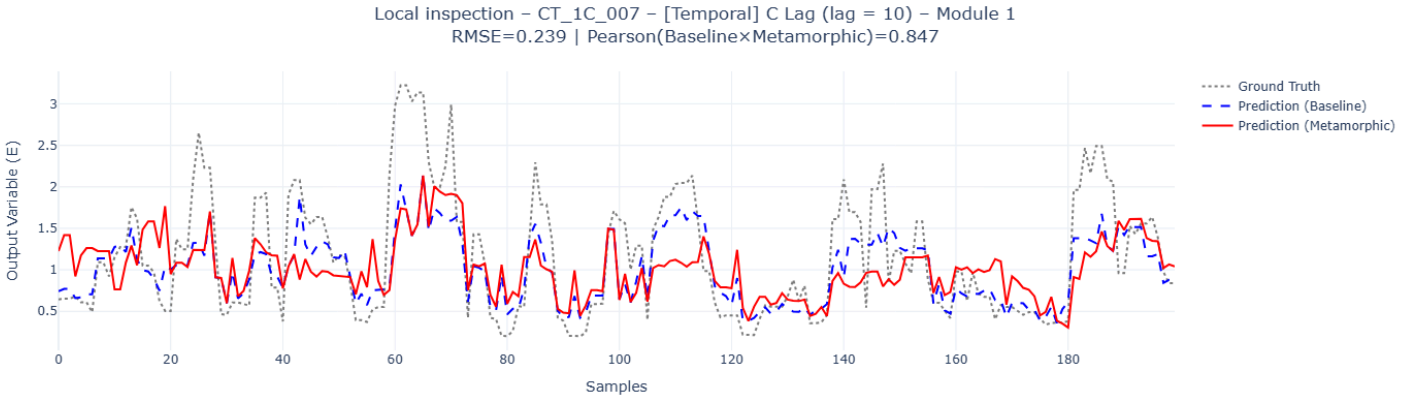
- **RMSE (Baseline × Metamorphic Prediction):** 0.3927
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.862
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.671



CT_1C_007 — Temporal Relation (C Lag = 10) — Module 1

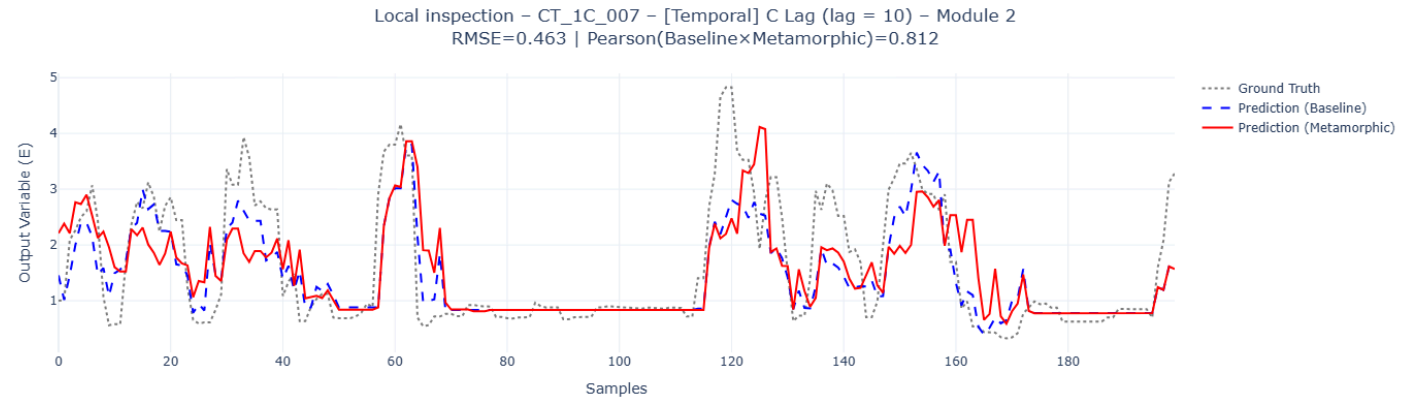
- **RMSE (Baseline × Metamorphic Prediction):** 0.2395
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.847

- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.733



CT_1C_007 — Temporal Relation (C Lag = 10) — Module 2

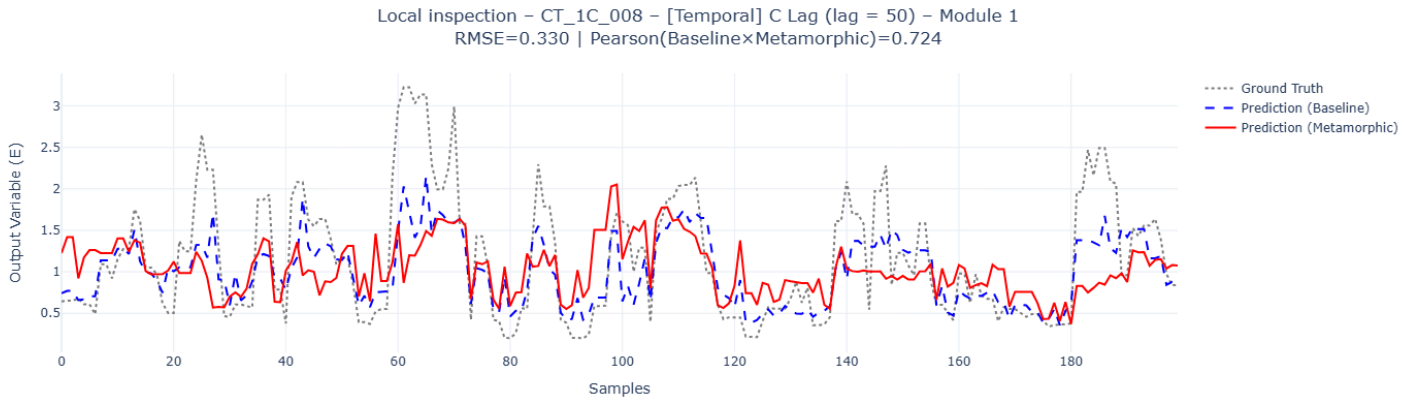
- **RMSE (Baseline × Metamorphic Prediction):** 0.4625
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.812
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.688



CT_1C_008 — Temporal Relation (C Lag = 50) — Module 1

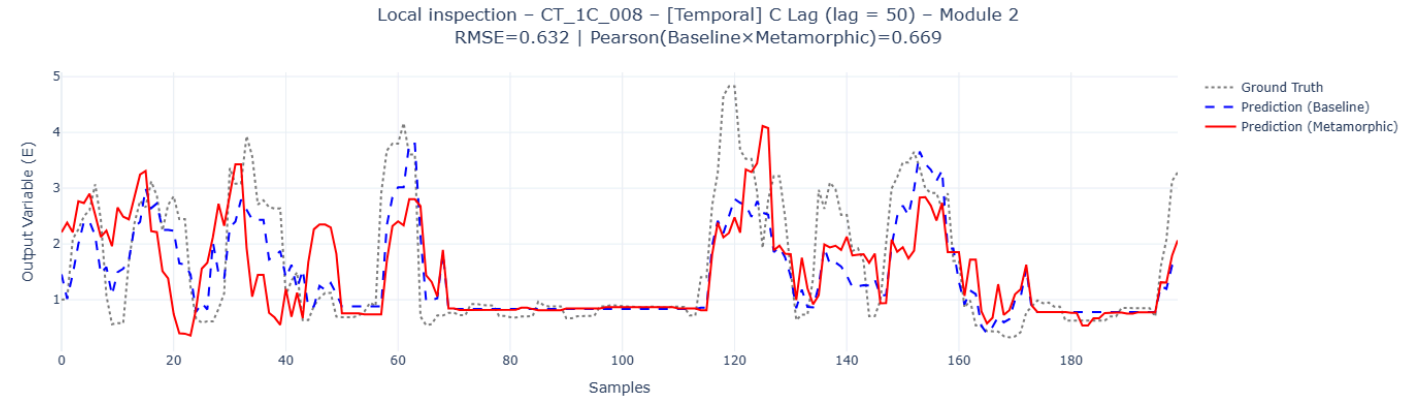
- **RMSE (Baseline × Metamorphic Prediction):** 0.3299
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.724

- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.649



CT_1C_008 — Temporal Relation (C Lag = 50) — Module 2

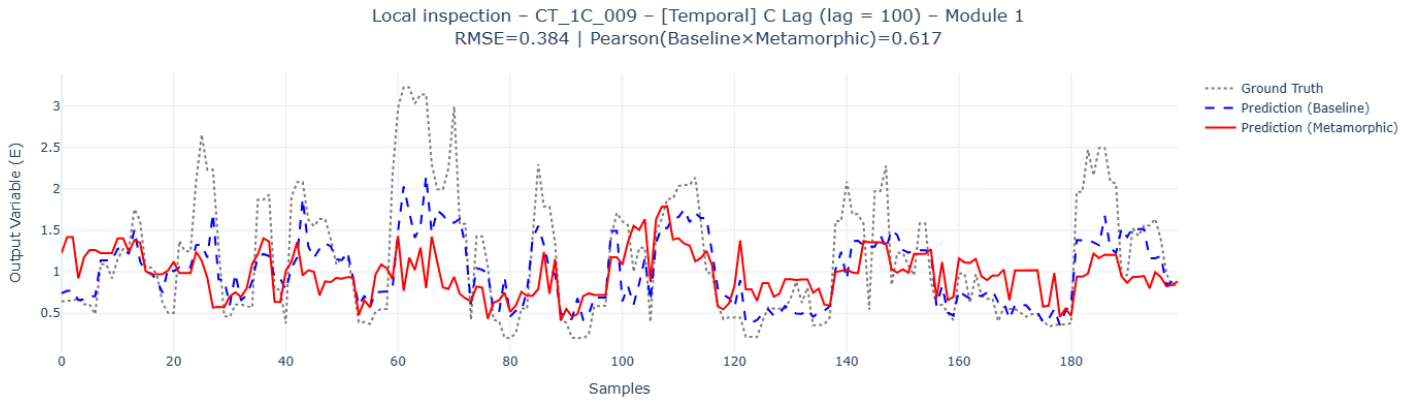
- **RMSE (Baseline × Metamorphic Prediction):** 0.6319
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.669
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.605



CT_1C_009 — Temporal Relation (C Lag = 100) — Module 1

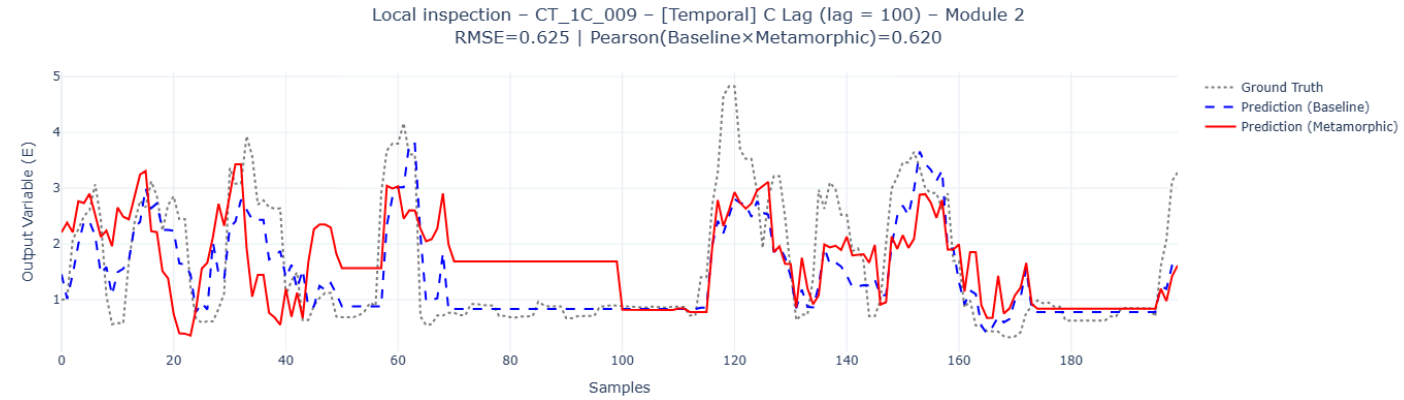
- **RMSE (Baseline × Metamorphic Prediction):** 0.3836
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.617

- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.567



CT_1C_009 — Temporal Relation (C Lag = 100) — Module 2

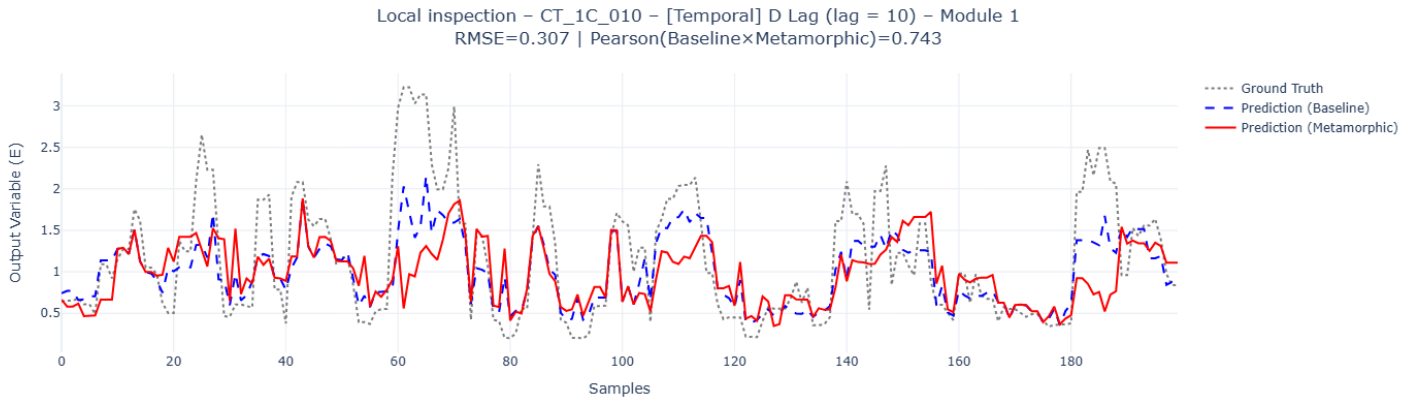
- **RMSE (Baseline × Metamorphic Prediction):** 0.6248
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.620
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.576



CT_1C_010 — Temporal Relation (D Lag = 10) — Module 1

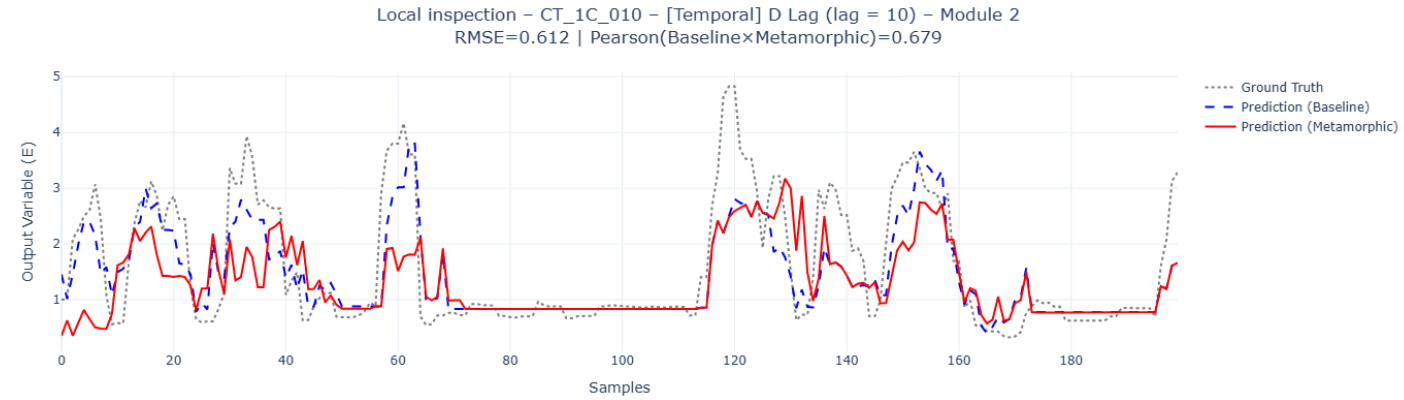
- **RMSE (Baseline × Metamorphic Prediction):** 0.3066
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.743

- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.589



CT_1C_010 — Temporal Relation (D Lag = 10) — Module 2

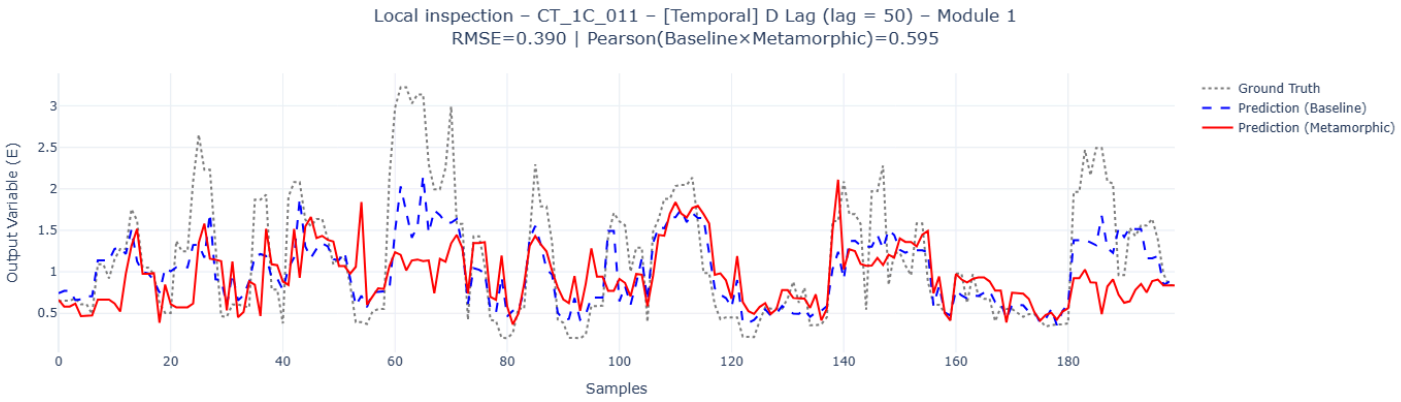
- **RMSE (Baseline × Metamorphic Prediction):** 0.6124
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.679
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.533



CT_1C_011 — Temporal Relation (D Lag = 50) — Module 1

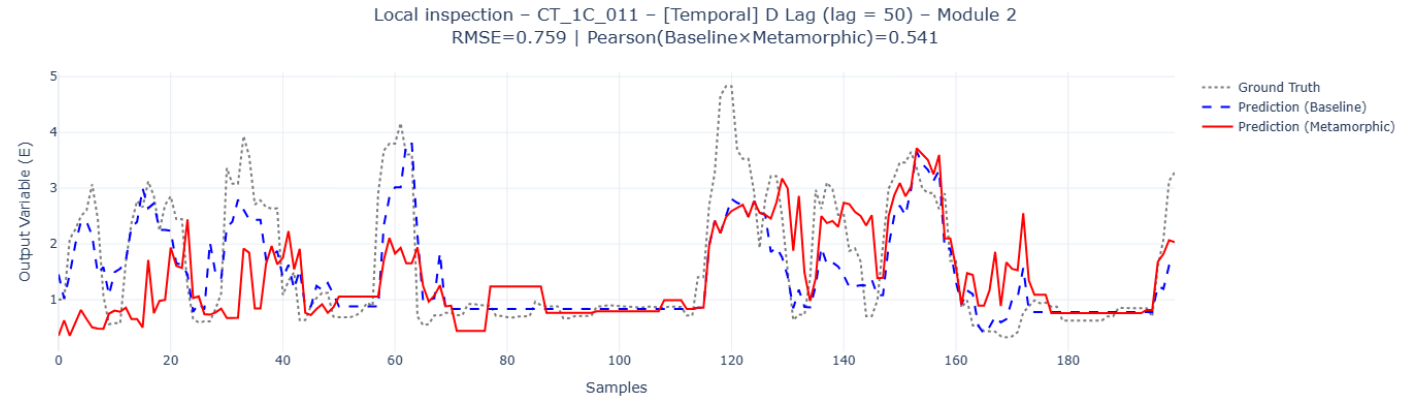
- **RMSE (Baseline × Metamorphic Prediction):** 0.3898
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.595

- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.493



CT_1C_011 — Temporal Relation (D Lag = 50) — Module 2

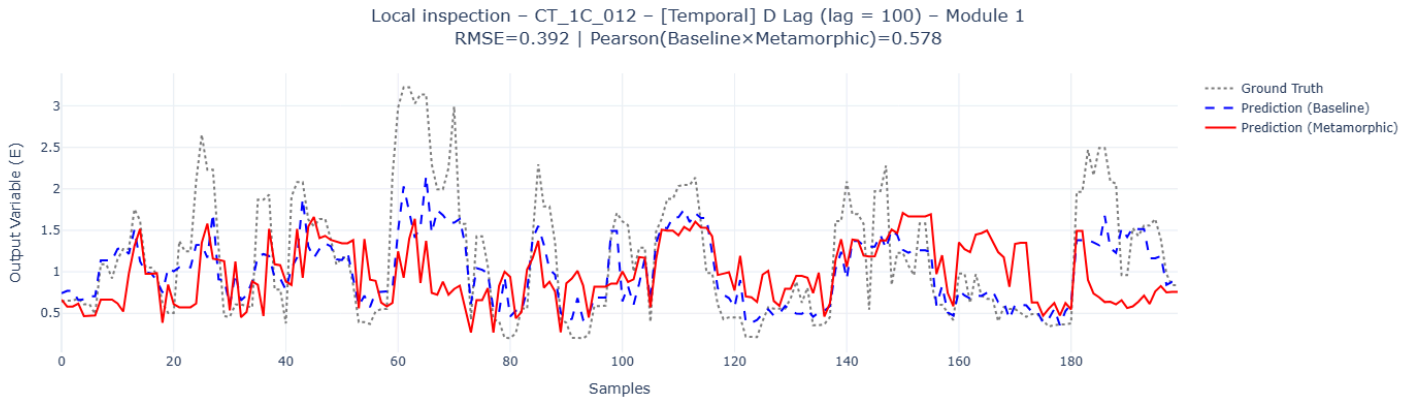
- **RMSE (Baseline × Metamorphic Prediction):** 0.7595
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.541
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.434



CT_1C_012 — Temporal Relation (D Lag = 100) — Module 1

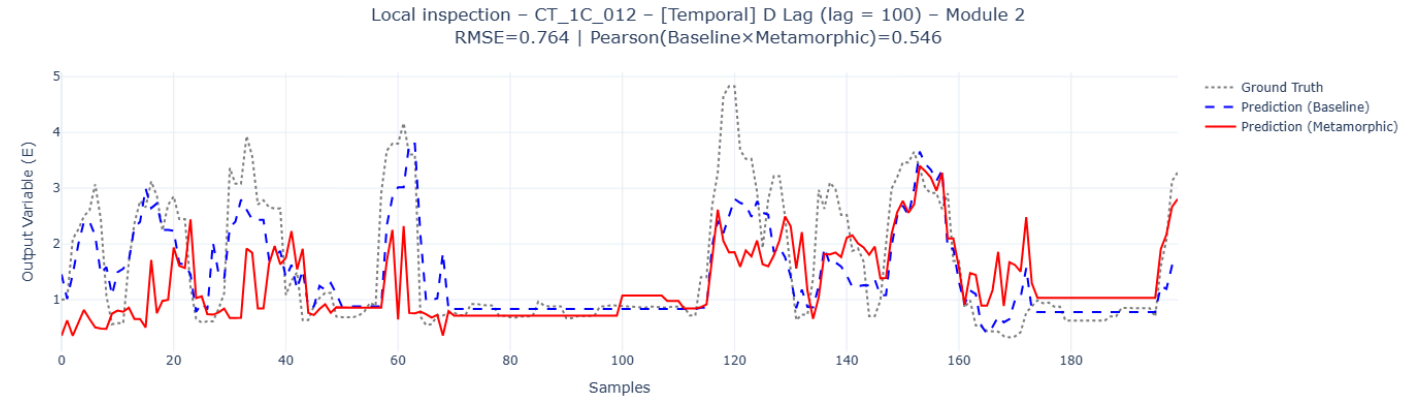
- **RMSE (Baseline × Metamorphic Prediction):** 0.3921
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.578

- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.499



CT_1C_012 — Temporal Relation (D Lag = 100) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.7636
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.546
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.449



Scenario 1D: Multiplicative Scaling of Individual Inputs

Metamorphic Relation Type: Multiplicative (M)

Description

This scenario evaluates how scaling the magnitude of individual abstract input variables affects the system output.

Each test case multiplies one input variable by a fixed factor (×20), while the remaining variables preserve their original values and structure.

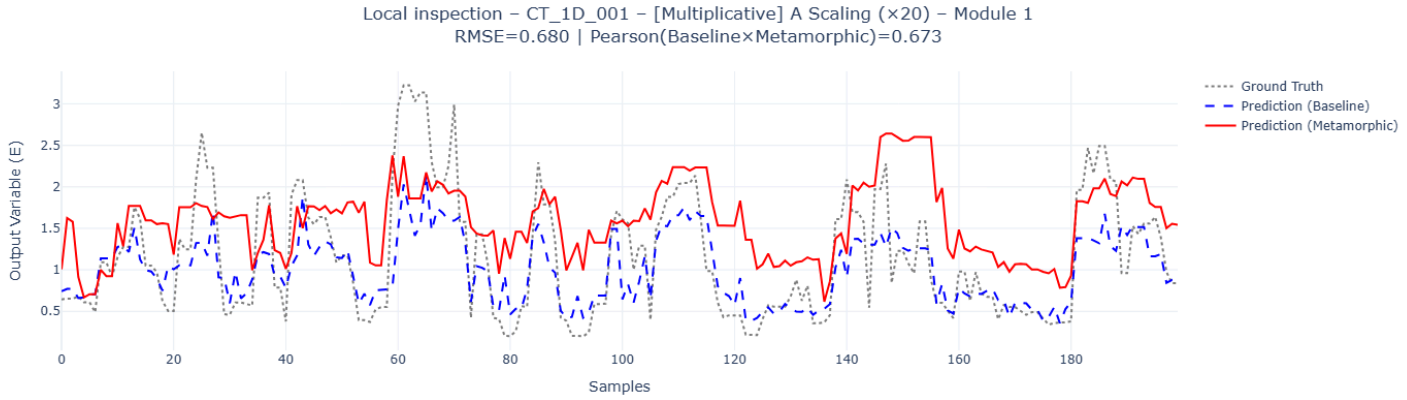
The objective is to observe whether increasing the magnitude of a single input interferes with the system’s output or execution, while preserving proportional relationships within that variable.

Test Cases

CT_1D_001 — Multiplicative Relation (A ×20) — Module 1

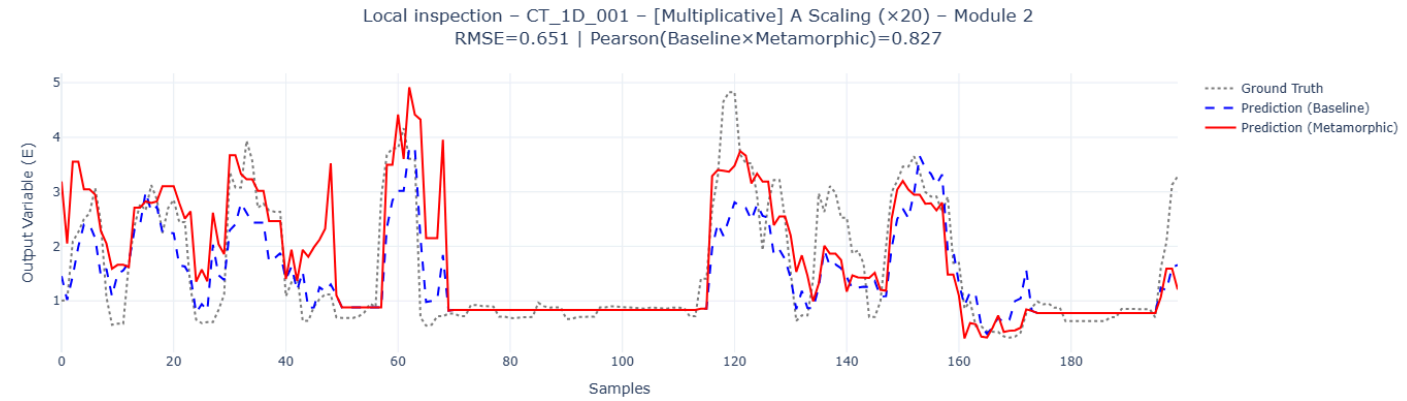
- **RMSE (Baseline × Metamorphic Prediction):** 0.6804

- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.673
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.575



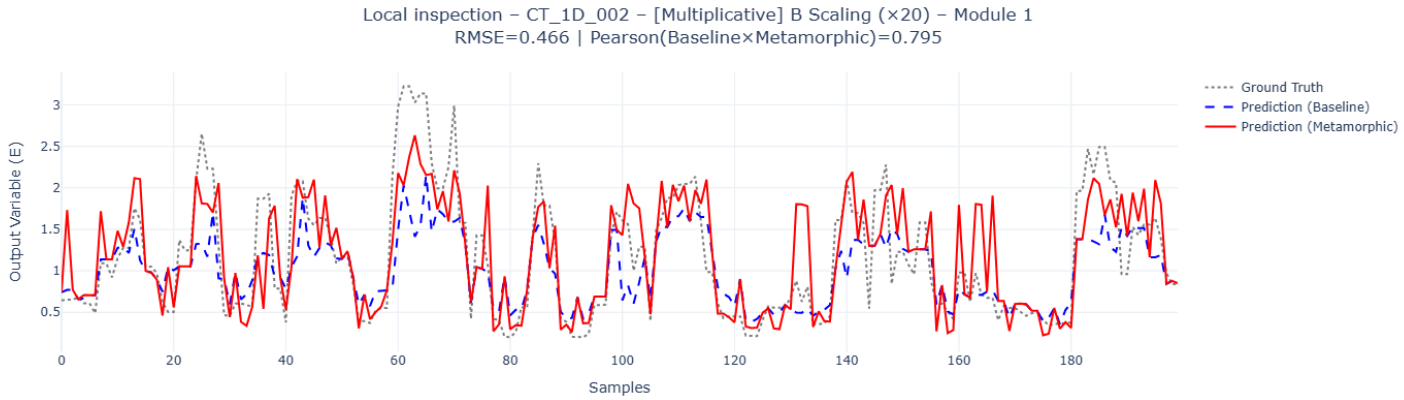
CT_1D_001 — Multiplicative Relation (A ×20) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.6509
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.827
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.680



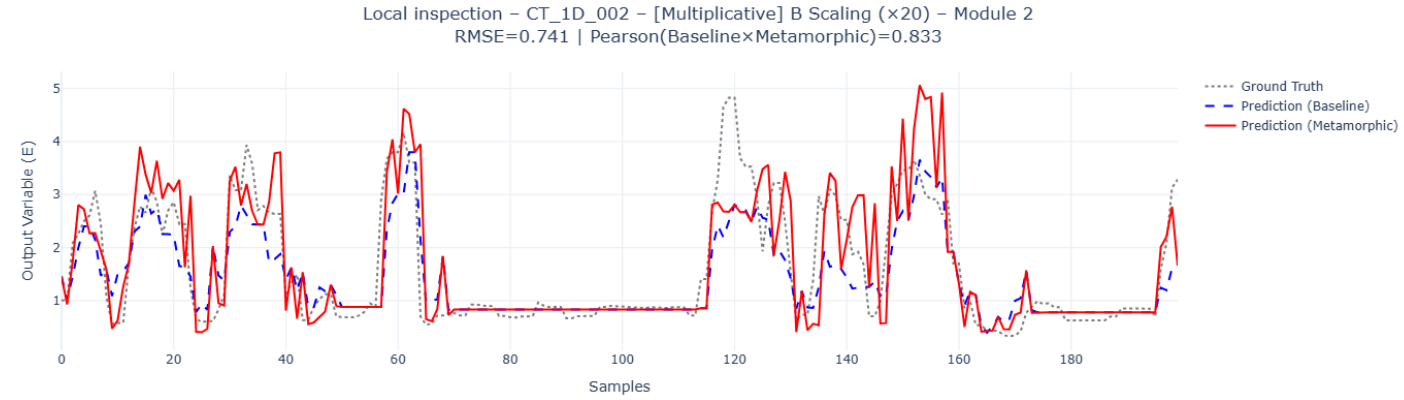
CT_1D_002 — Multiplicative Relation (B ×20) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.4663
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.795
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.780



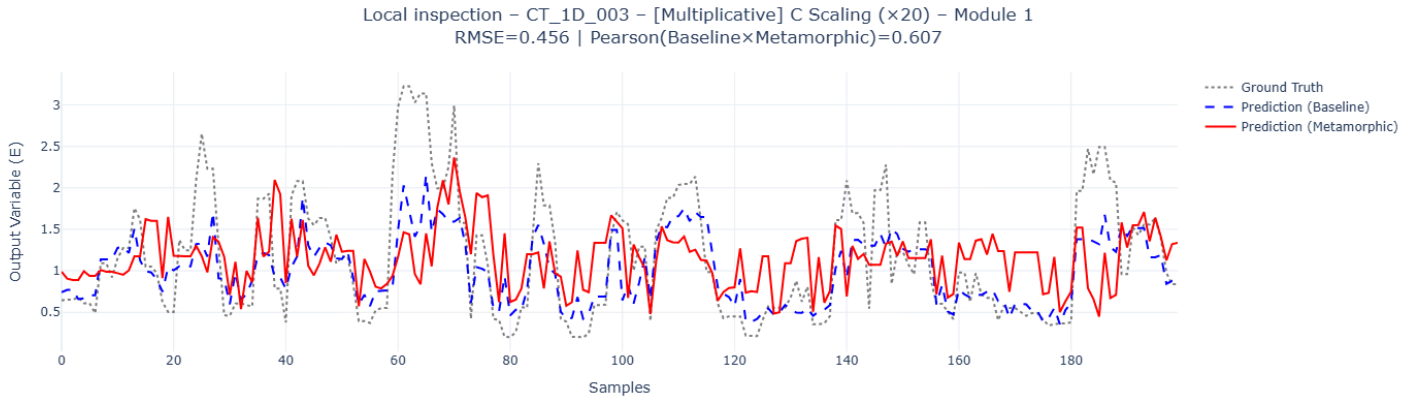
CT_1D_002 — Multiplicative Relation (B ×20) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.7408
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.833
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.778



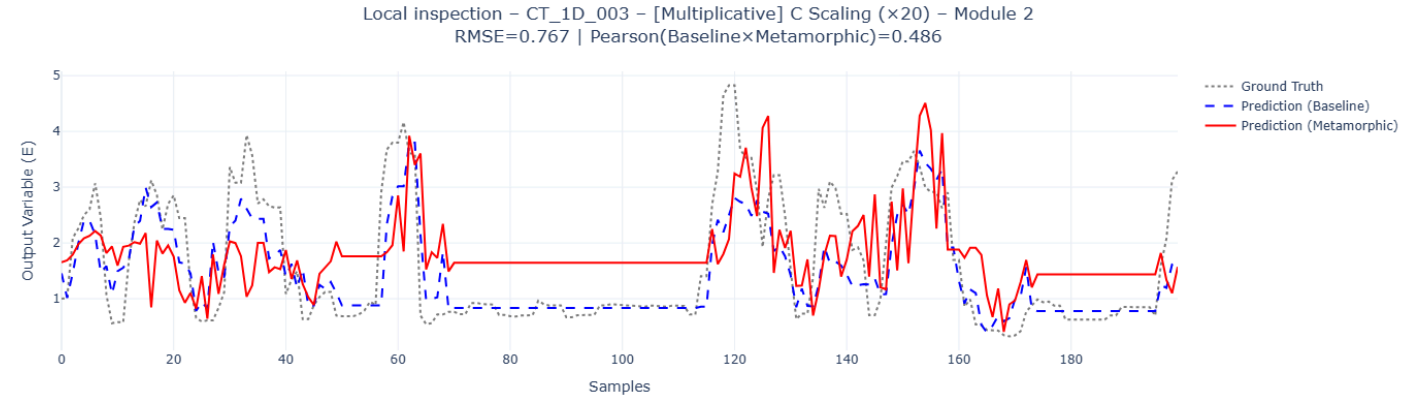
CT_1D_003 — Multiplicative Relation (C ×20) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.4562
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.607
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.528



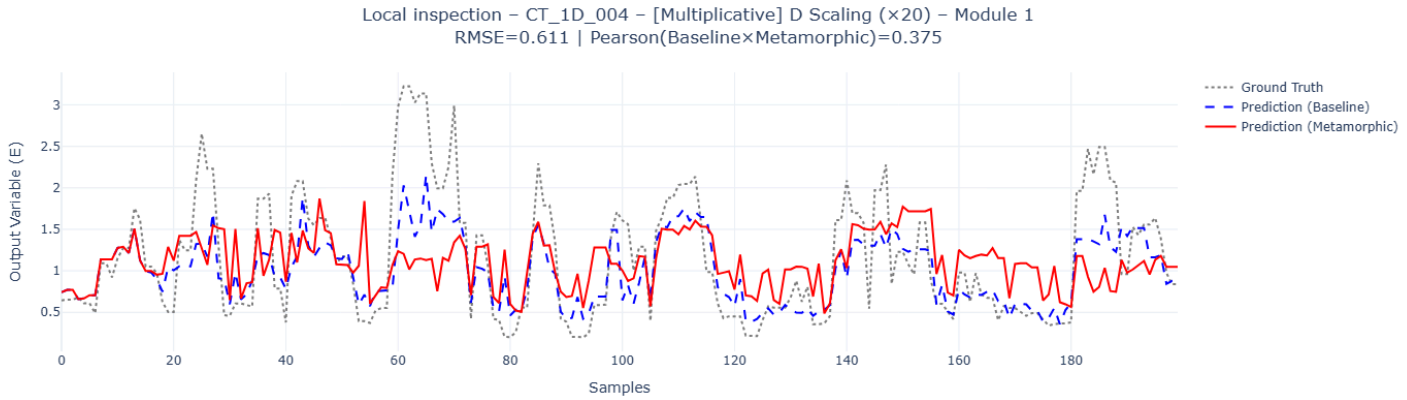
CT_1D_003 — Multiplicative Relation (C ×20) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.7673
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.486
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.396



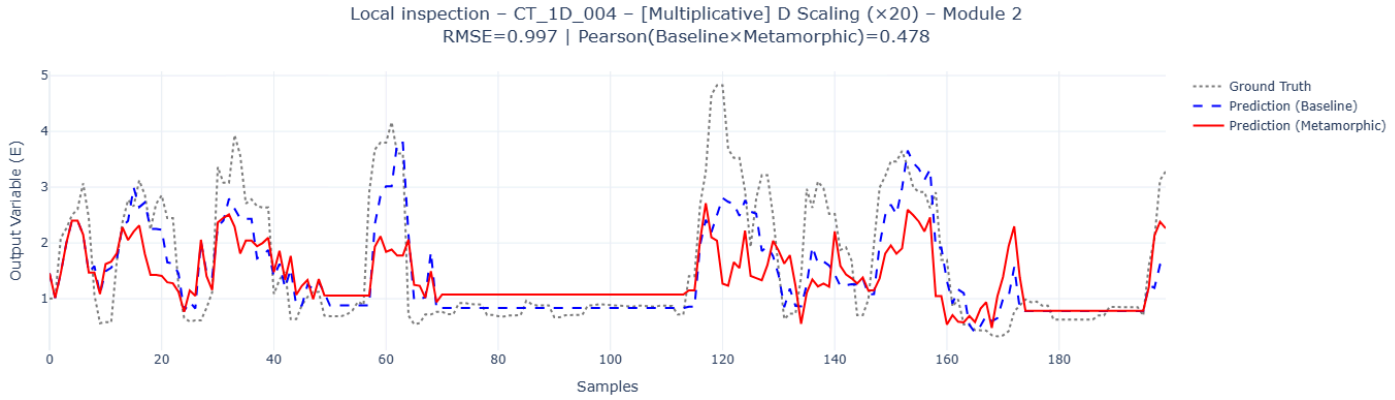
CT_1D_004 — Multiplicative Relation (D ×20) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.6111
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.375
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.334



CT_1D_004 — Multiplicative Relation (D ×20) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.9966
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.478
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.390



Scenario 1E: Gaussian Noise Injection into Individual Inputs

Metamorphic Relation Type: Sustainable (S)

Description

In this scenario, the evaluator analyzes the effect of injecting Gaussian noise into individual abstract input variables.

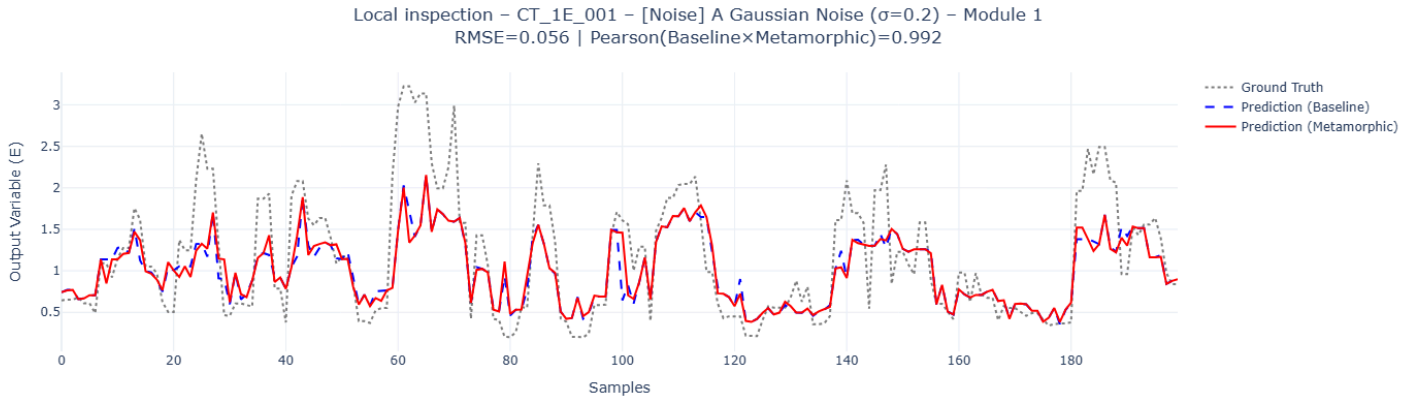
Each test case adds noise with moderate variance (σ = 0.2) to one input variable, while preserving the structure, dimensionality, and temporal organization of the dataset.

The objective is to observe whether localized stochastic perturbations interfere with the system output or disrupt execution, while maintaining the overall structure of the input data.

Test Cases

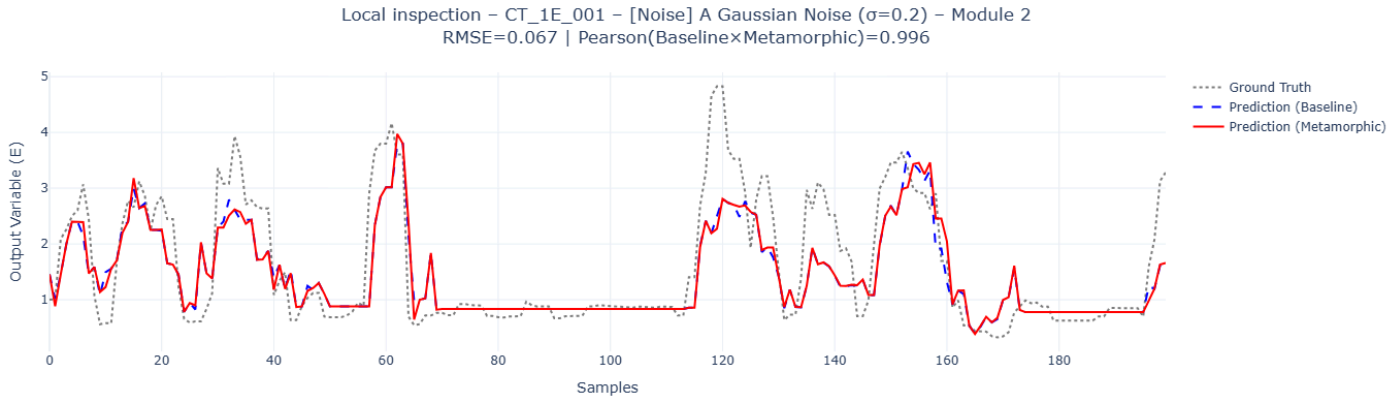
CT_1E_001 — Sustainable Relation (Gaussian Noise on A, σ = 0.2) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.0565
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.992
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.815



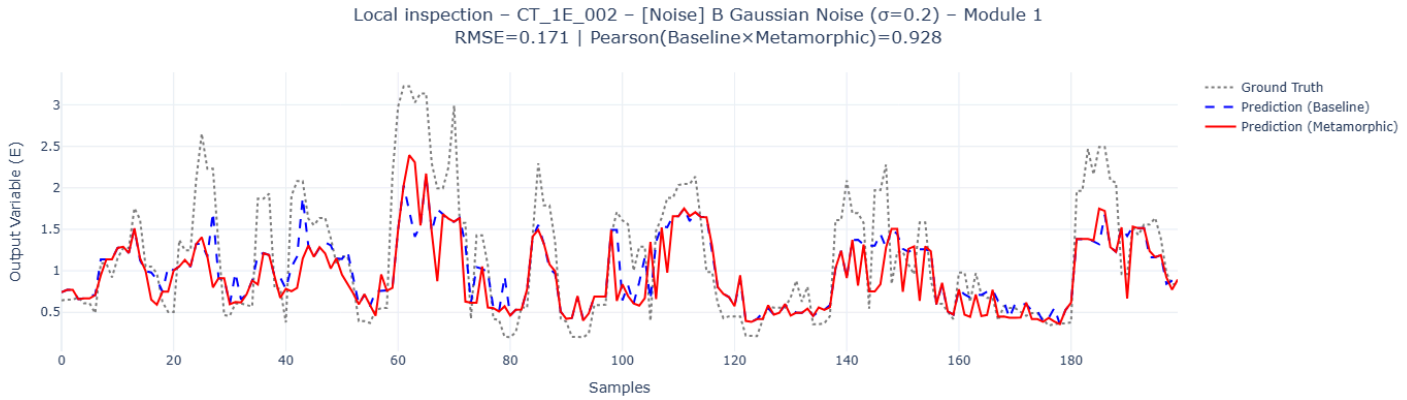
CT_1E_001 — Sustainable Relation (Gaussian Noise on A, σ = 0.2) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.0670
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.996
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.805



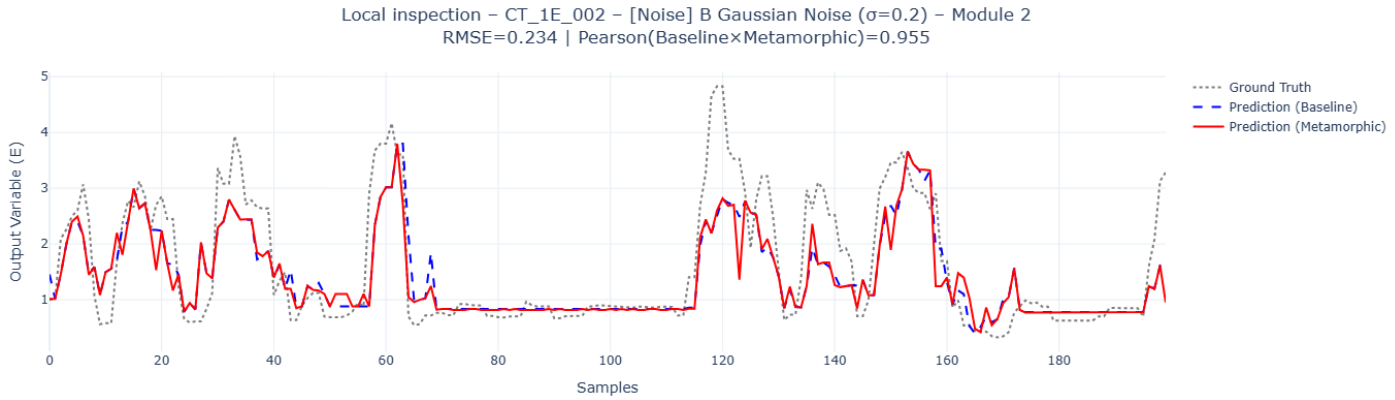
CT_1E_002 — Sustainable Relation (Gaussian Noise on B, σ = 0.2) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.1705
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.928
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.786



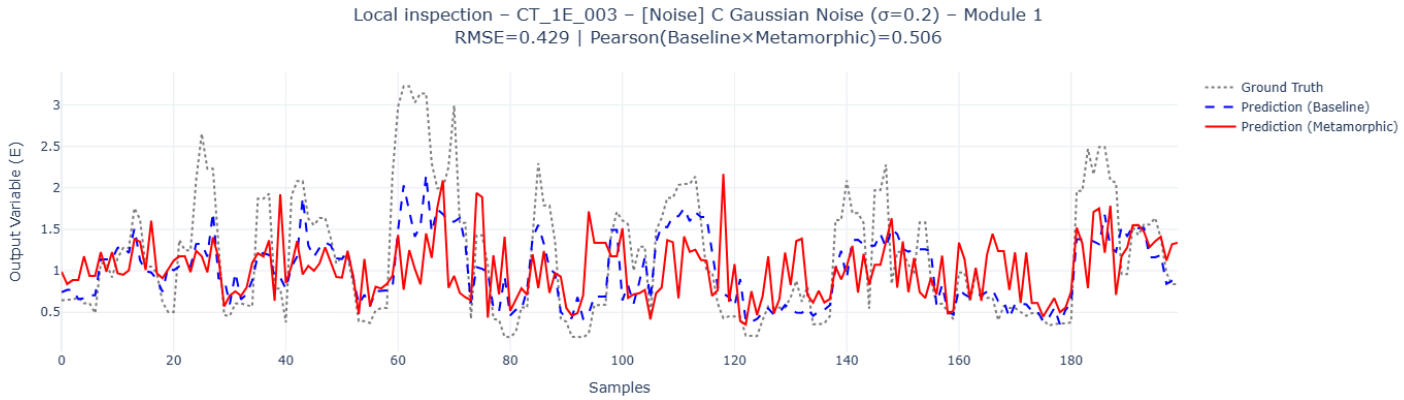
CT_1E_002 — Sustainable Relation (Gaussian Noise on B, σ = 0.2) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.2342
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.955
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.780



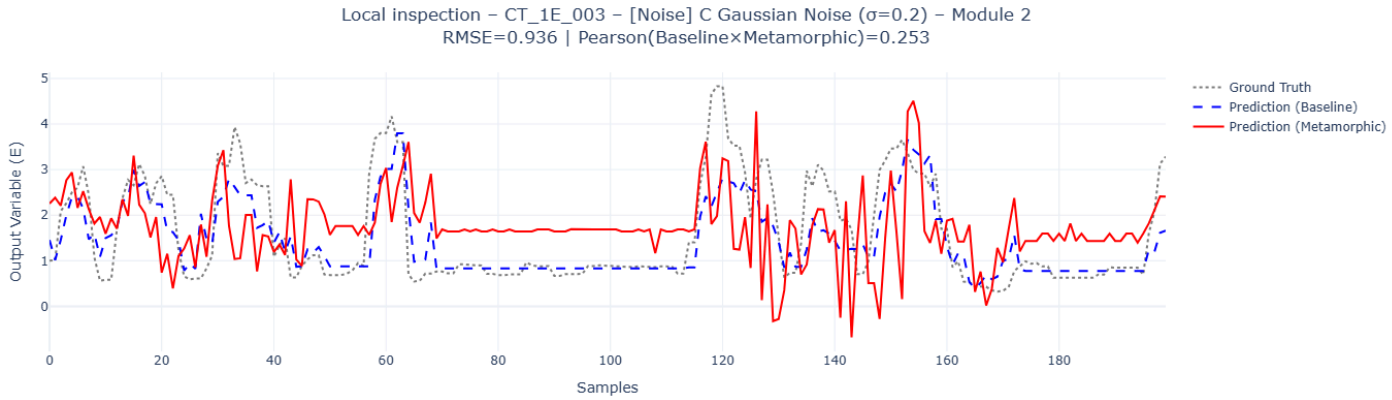
CT_1E_003 — Sustainable Relation (Gaussian Noise on C, σ = 0.2) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.4291
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.506
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.451



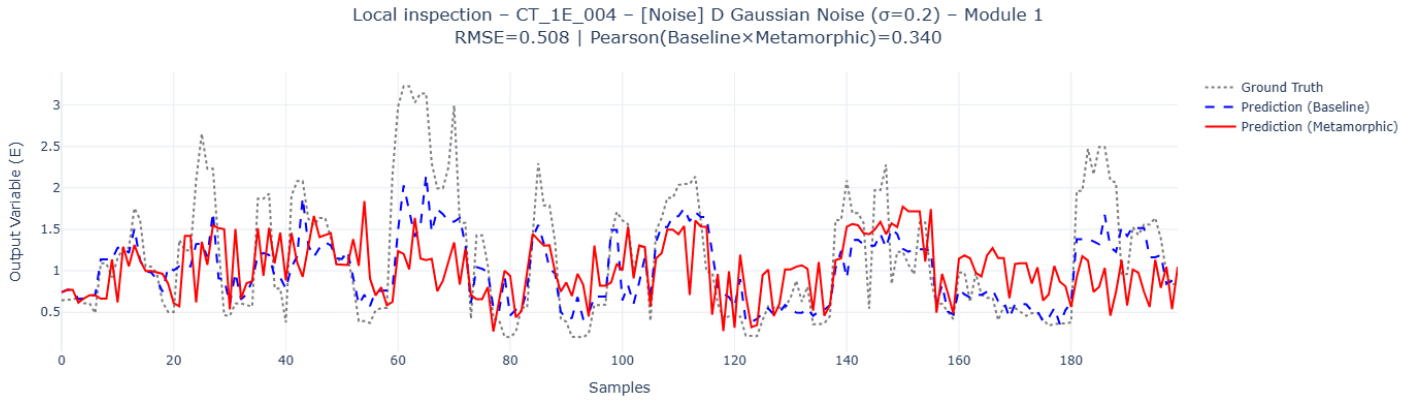
CT_1E_003 — Sustainable Relation (Gaussian Noise on C, σ = 0.2) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.9360
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.253
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.194



CT_1E_004 — Sustainable Relation (Gaussian Noise on D, σ = 0.2) — Module 1

- **RMSE (Baseline × Metamorphic Prediction):** 0.5078
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.340
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.302



CT_1E_004 — Sustainable Relation (Gaussian Noise on D, σ = 0.2) — Module 2

- **RMSE (Baseline × Metamorphic Prediction):** 0.8754
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.432
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.341