

# **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.

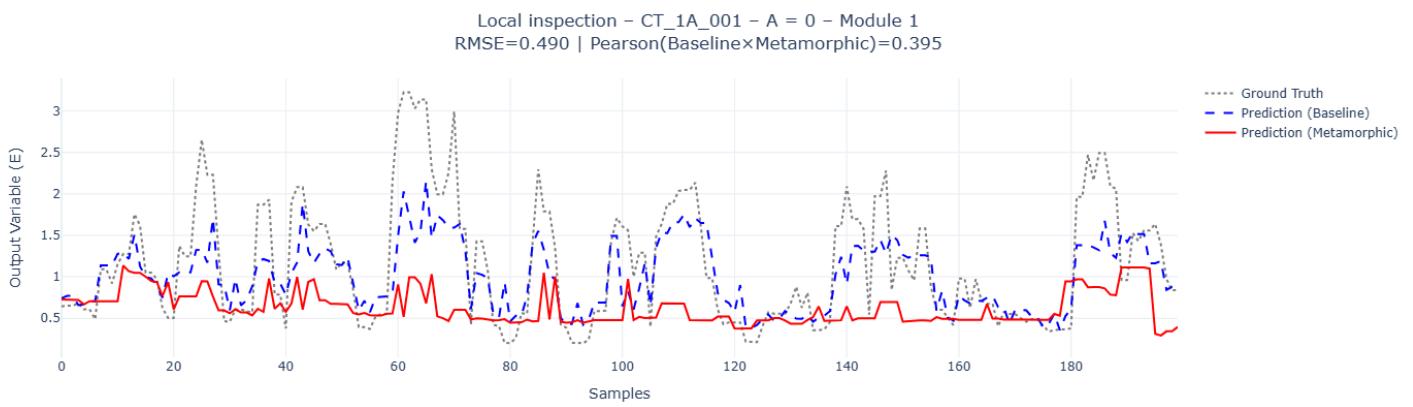
Each execution with modified data produces a Metamorphic Prediction, which is compared against the Baseline Prediction obtained from the unmodified reference dataset using quantitative metrics.

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

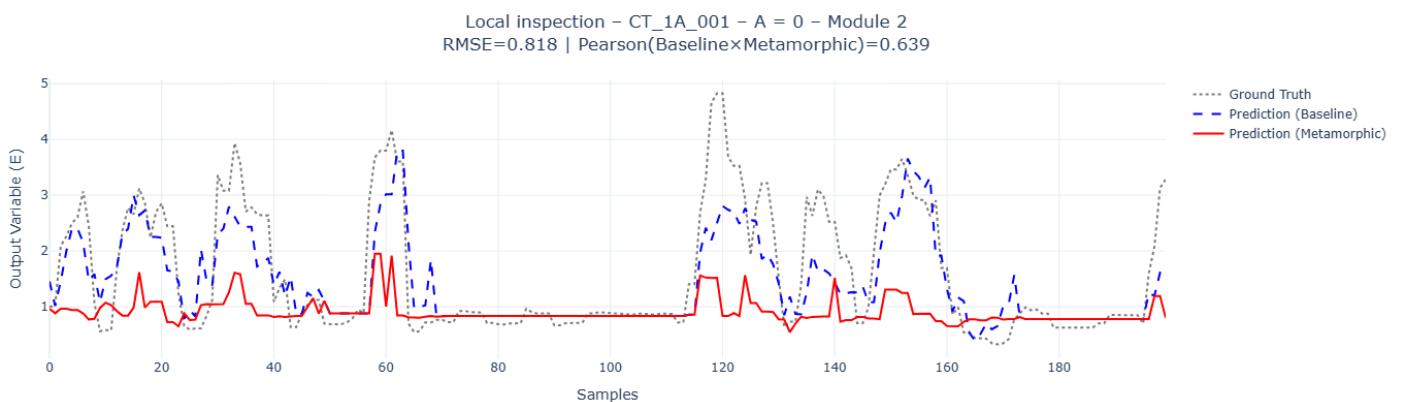
### CT\_1A\_001 – Exclusive Relation (A = 0) – Module 1

- 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

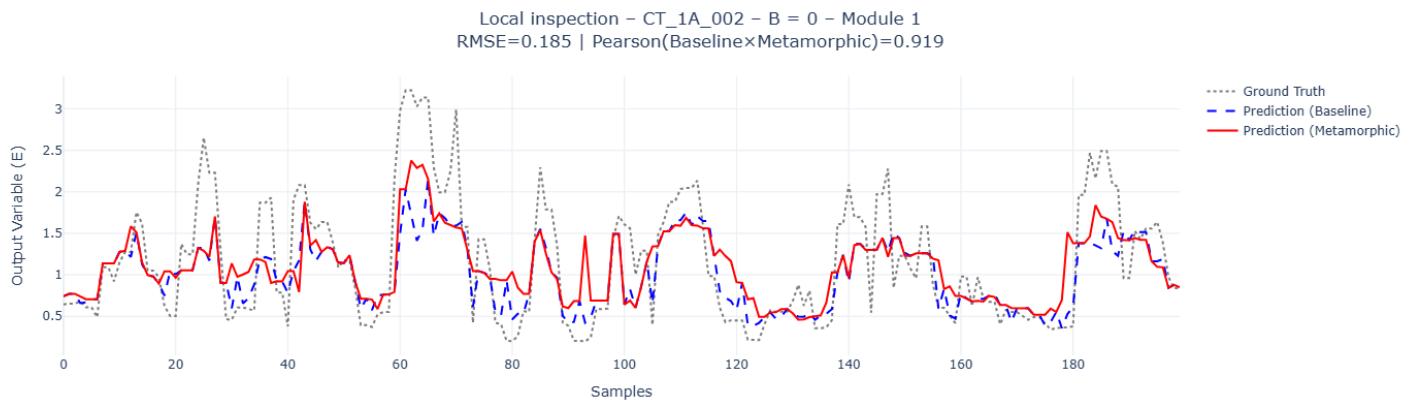
- RMSE (Baseline × Metamorphic Prediction): 0.8179
- Pearson Correlation (Baseline × Metamorphic Prediction): 0.639
- Pearson Correlation (Ground Truth × Metamorphic Prediction): 0.537



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## **CT\_1A\_002 – Exclusive Relation (B = 0) – Module 1**

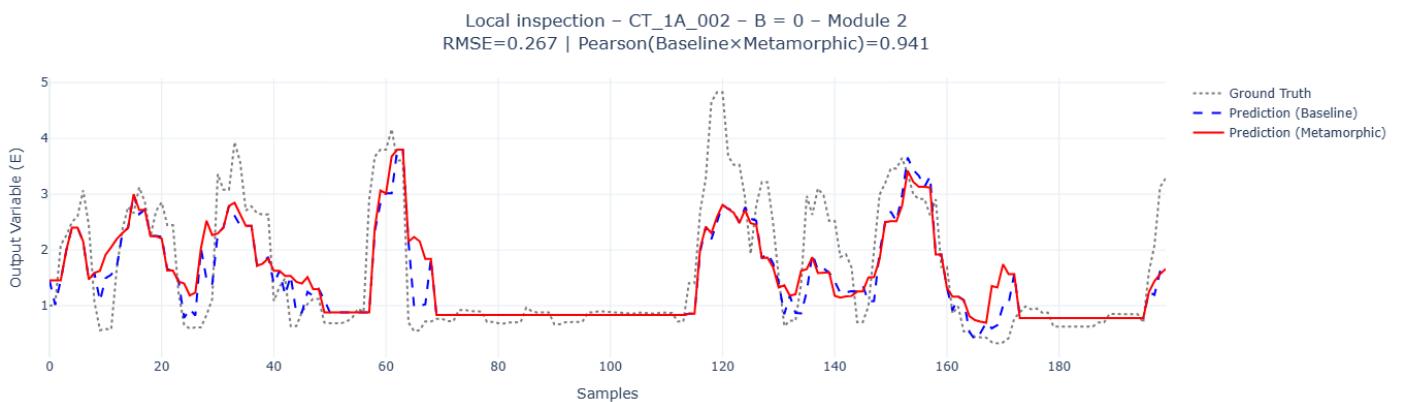
- RMSE (Baseline × Metamorphic Prediction): 0.1847
- Pearson Correlation (Baseline × Metamorphic Prediction): 0.919
- Pearson Correlation (Ground Truth × Metamorphic Prediction): 0.779



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## **CT\_1A\_002 – Exclusive Relation (B = 0) – Module 2**

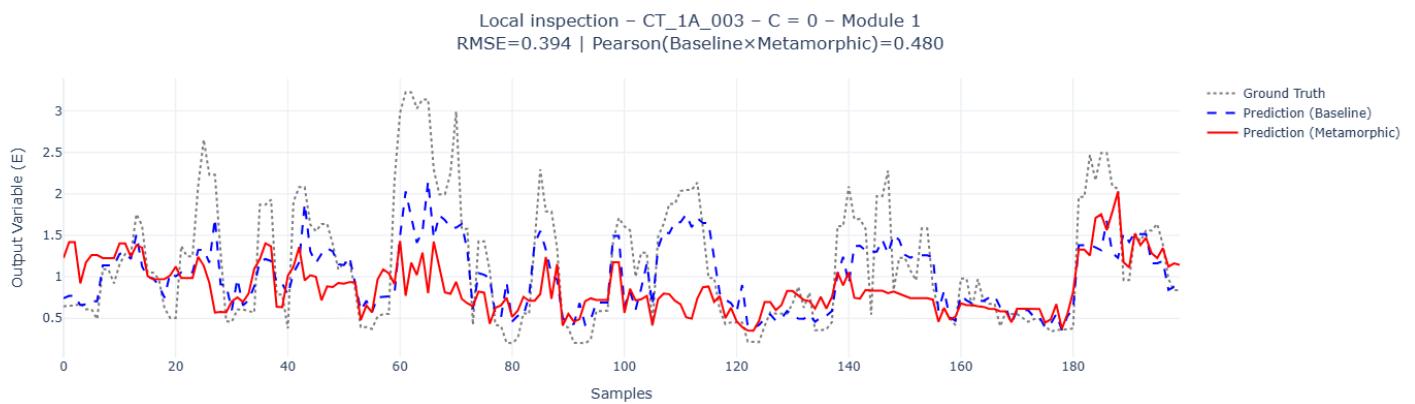
- RMSE (Baseline × Metamorphic Prediction): 0.2673
- Pearson Correlation (Baseline × Metamorphic Prediction): 0.941
- Pearson Correlation (Ground Truth × Metamorphic Prediction): 0.733



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## **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

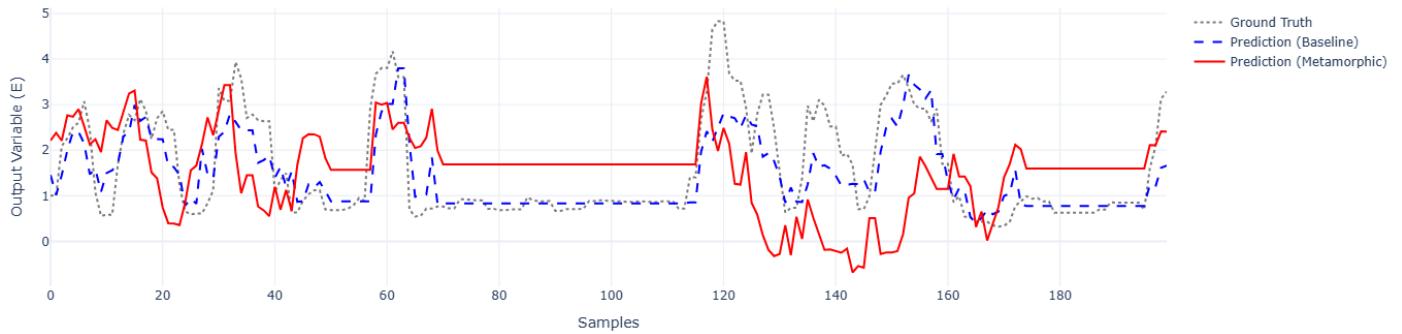


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## **CT\_1A\_003 – Exclusive Relation (C = 0) – Module 2**

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

Local inspection – CT\_1A\_003 – C = 0 – Module 2  
RMSE=1.075 | Pearson(Baseline×Metamorphic)=0.030

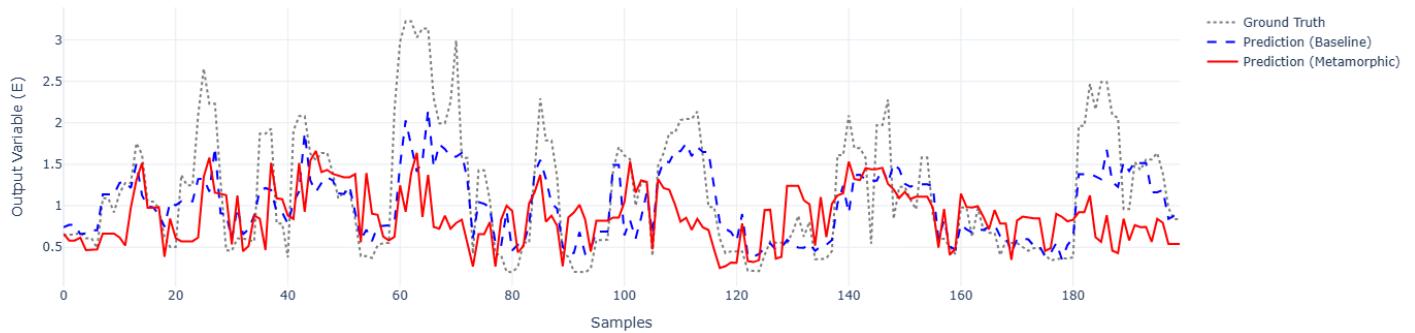


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### CT\_1A\_004 – Exclusive Relation (D = 0) – Module 1

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

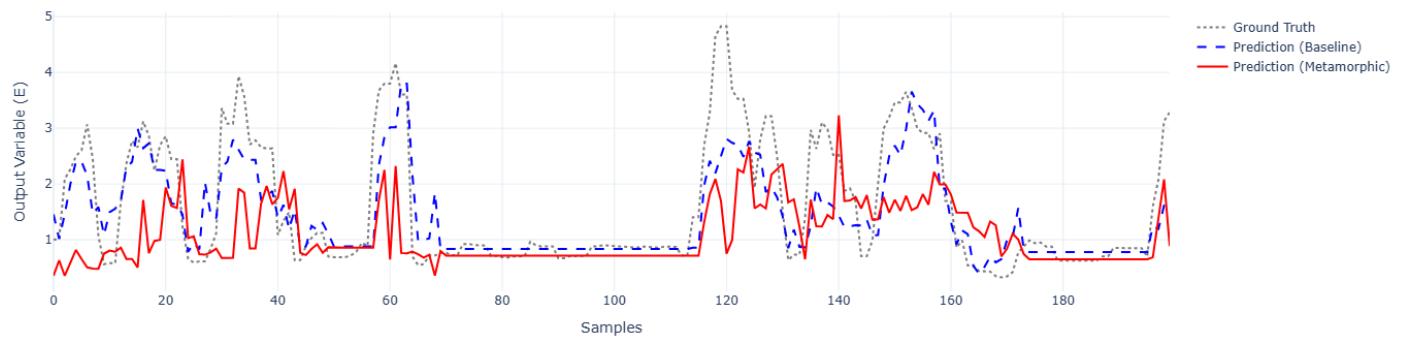
Local inspection – CT\_1A\_004 – D = 0 – Module 1  
RMSE=0.424 | Pearson(Baseline×Metamorphic)=0.385



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### 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.

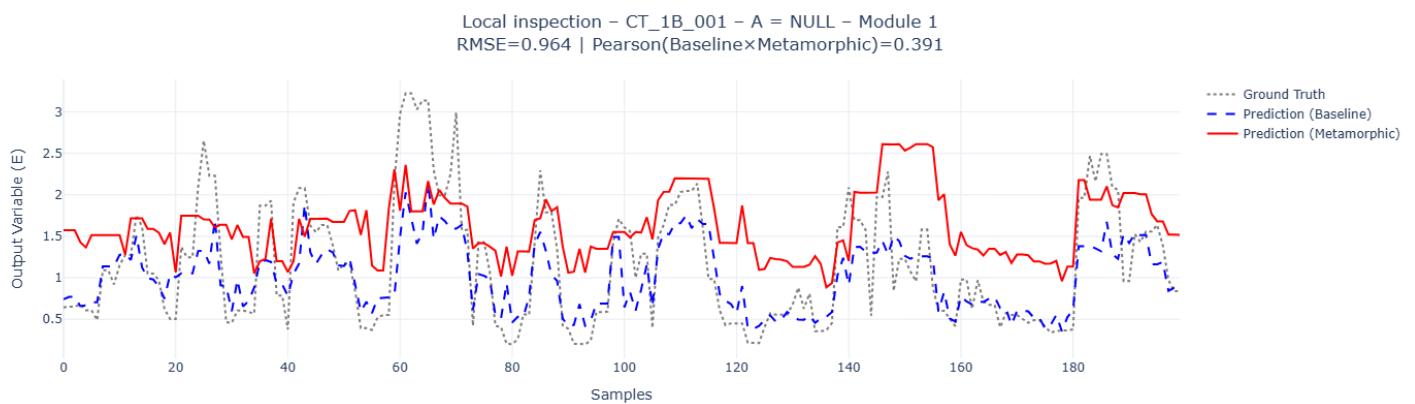
Each test case removes one input variable from effective participation in the computation by replacing its value with NULL, while all other inputs remain unchanged.

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

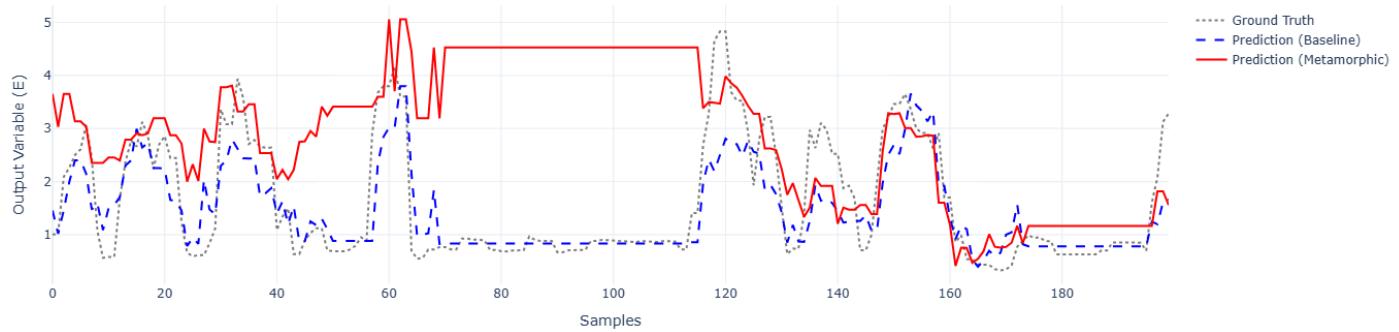
- RMSE (Baseline × Metamorphic Prediction): 0.9639
- Pearson Correlation (Baseline × Metamorphic Prediction): 0.391
- Pearson Correlation (Ground Truth × Metamorphic Prediction): 0.347



### 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

Local inspection - CT\_1B\_001 - A = NULL - Module 2  
RMSE=1.261 | Pearson(Baseline×Metamorphic)=0.493

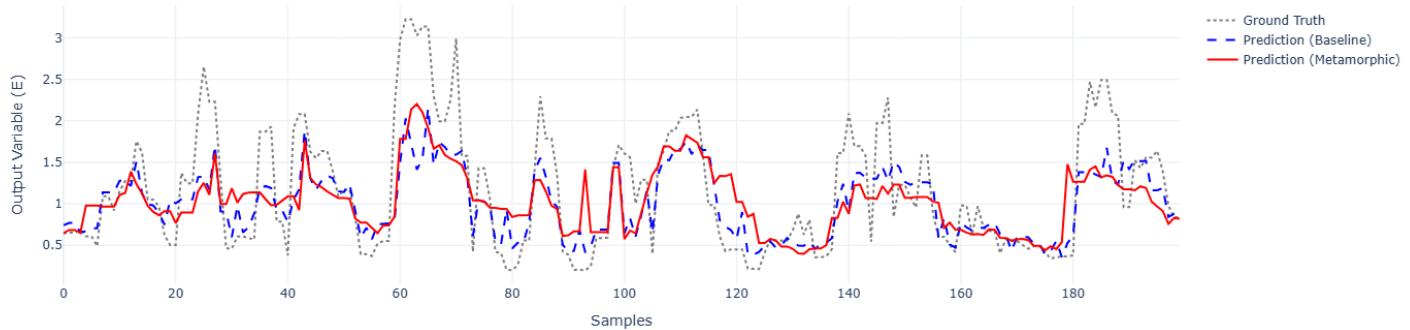


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### **CT\_1B\_002 – Exclusive Relation (B = NULL) – Module 1**

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

Local inspection - CT\_1B\_002 - B = NULL - Module 1  
RMSE=0.195 | Pearson(Baseline×Metamorphic)=0.900

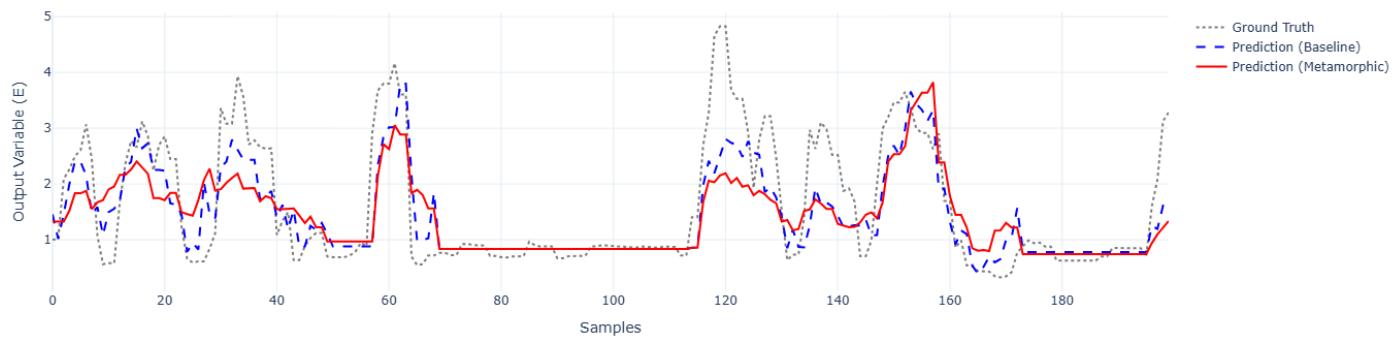


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### **CT\_1B\_002 – Exclusive Relation (B = NULL) – Module 2**

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

Local inspection - CT\_1B\_002 - B = NULL - Module 2  
RMSE=0.333 | Pearson(Baseline×Metamorphic)=0.906

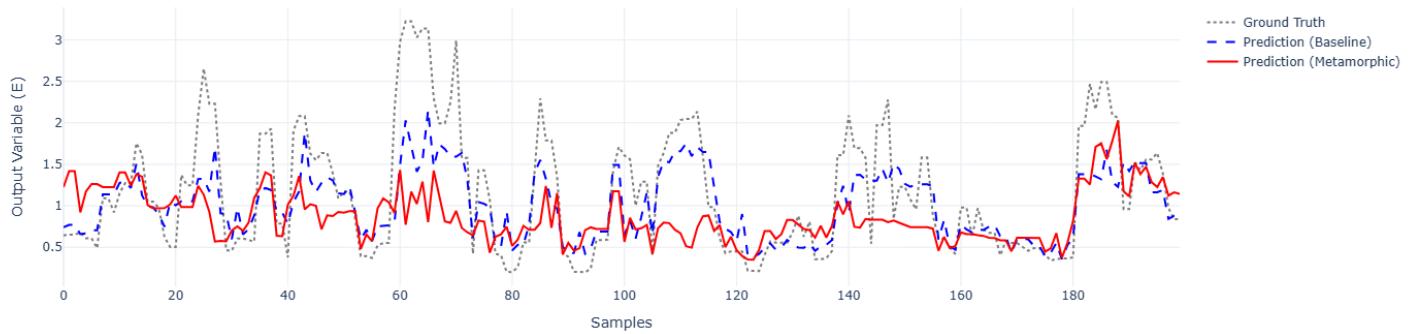


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### CT\_1B\_003 – Exclusive Relation (C = NULL) – Module 1

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

Local inspection - CT\_1B\_003 - C = NULL - Module 1  
RMSE=0.394 | Pearson(Baseline×Metamorphic)=0.480

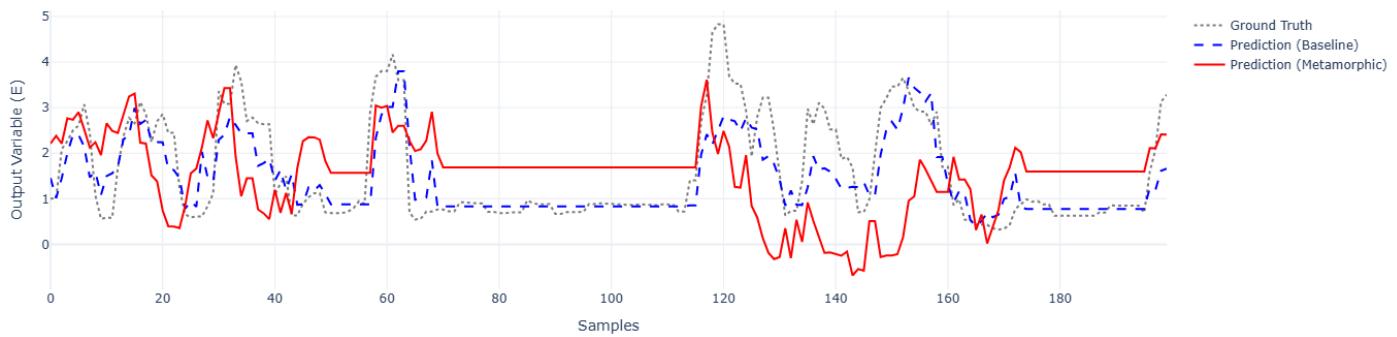


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### CT\_1B\_003 – Exclusive Relation (C = NULL) – Module 2

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

Local inspection - CT\_1B\_003 - C = NULL - Module 2  
RMSE=1.075 | Pearson(Baseline×Metamorphic)=0.030

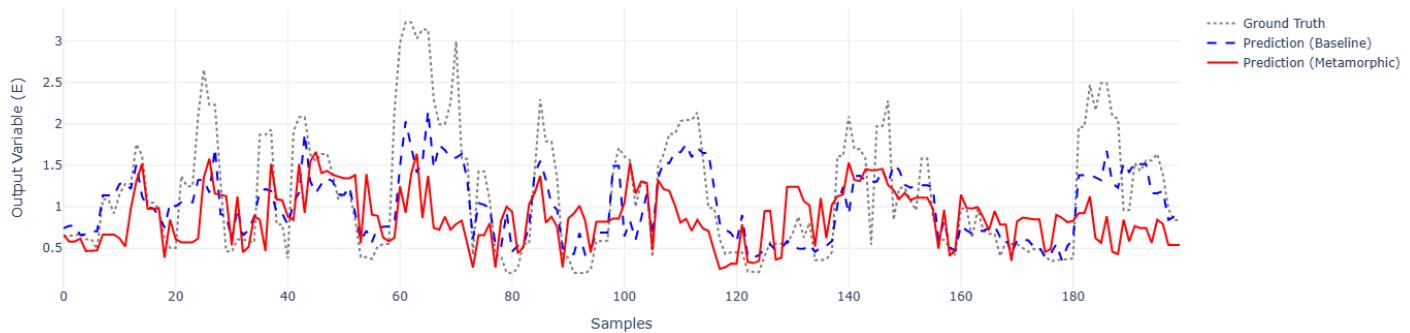


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### CT\_1B\_004 – Exclusive Relation (D = NULL) – Module 1

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

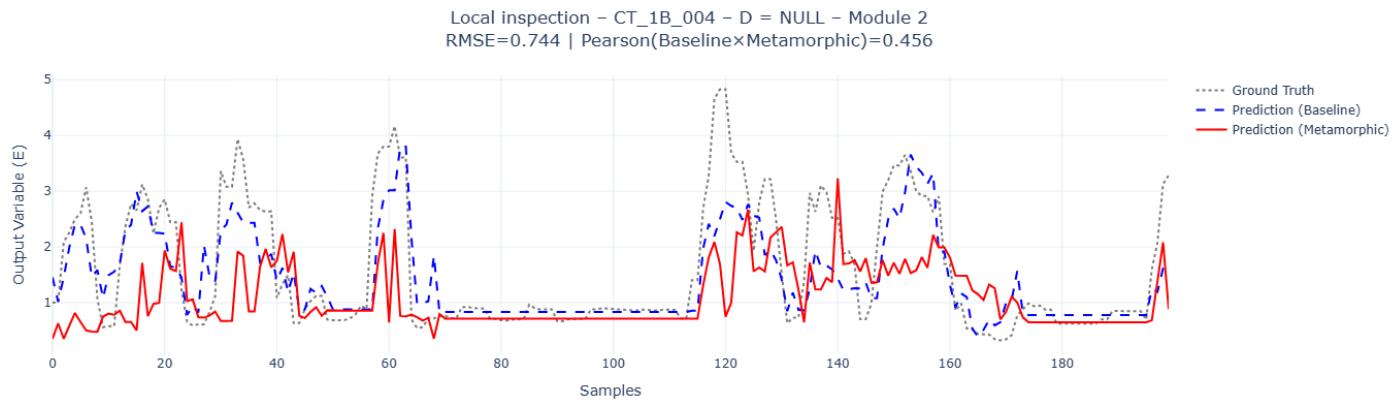
Local inspection - CT\_1B\_004 - D = NULL - Module 1  
RMSE=0.424 | Pearson(Baseline×Metamorphic)=0.385



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### 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.

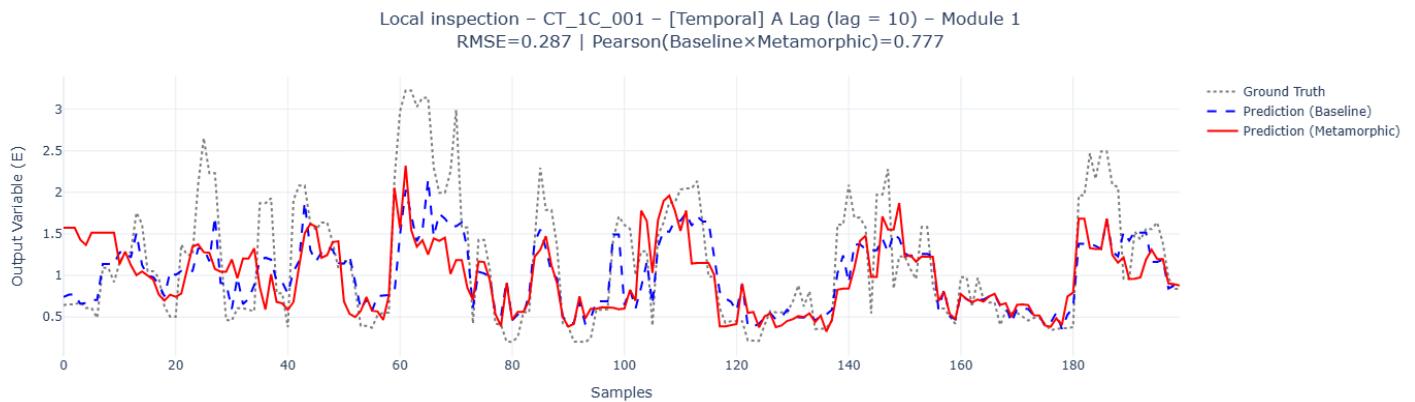
Each test case introduces a temporal lag of 10, 50, or 100 samples to one input variable, while preserving the original ordering of the remaining inputs.

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

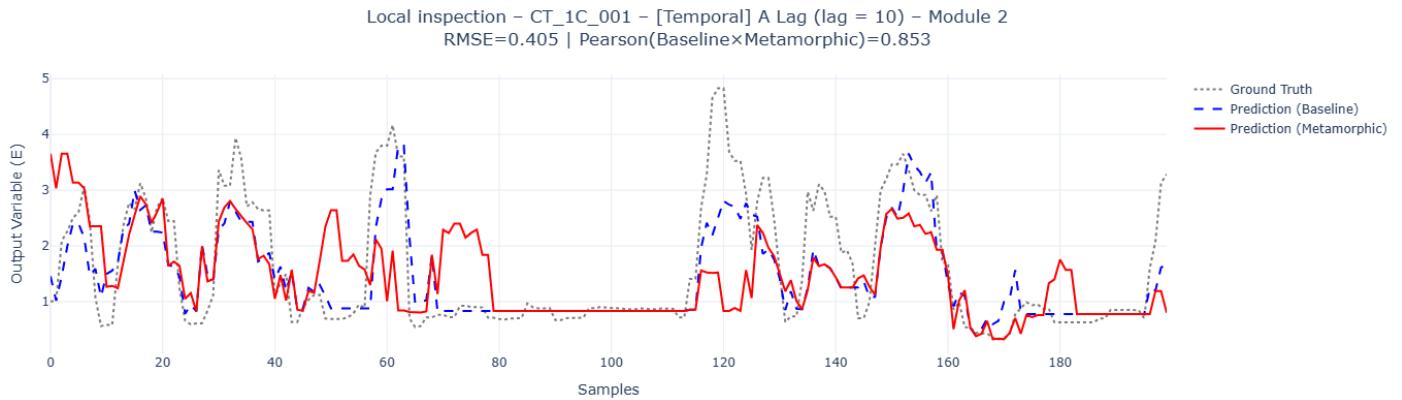


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### **CT\_1C\_001 – Temporal Relation (A Lag = 10) – Module 2**

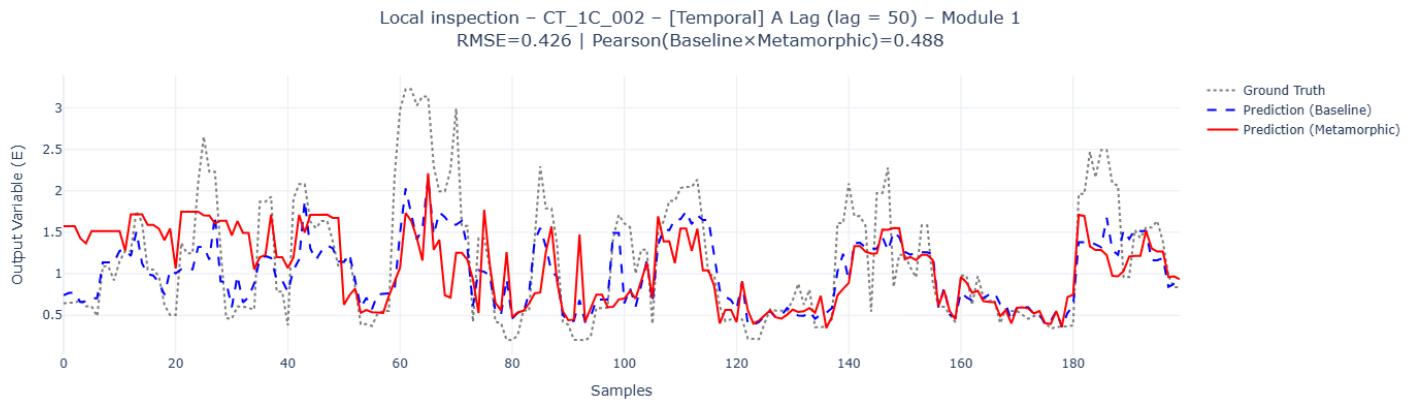
- RMSE (Baseline × Metamorphic Prediction): 0.4046

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



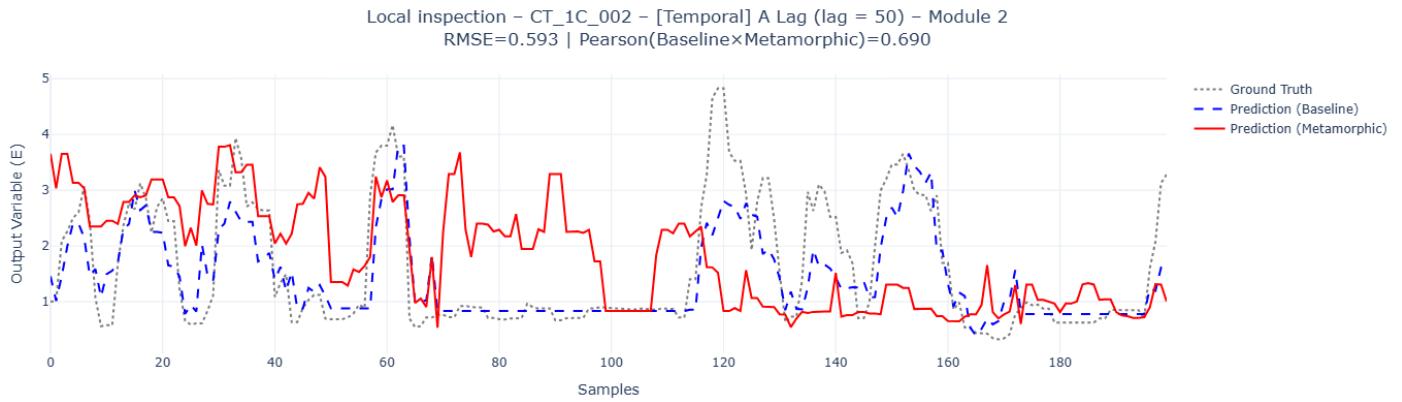
### **CT\_1C\_002 – Temporal Relation (A Lag = 50) – Module 1**

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



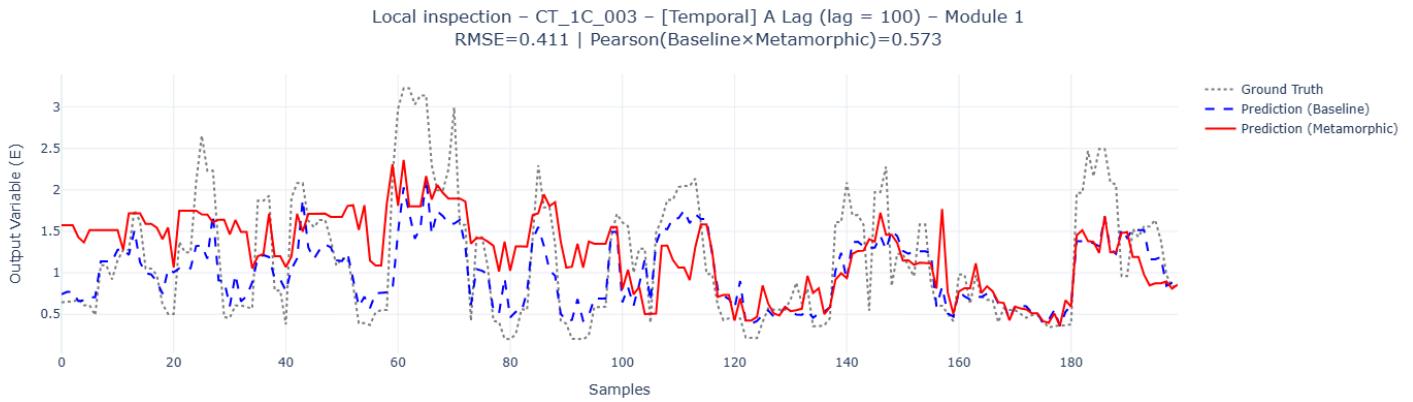
### **CT\_1C\_002 – Temporal Relation (A Lag = 50) – Module 2**

- 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

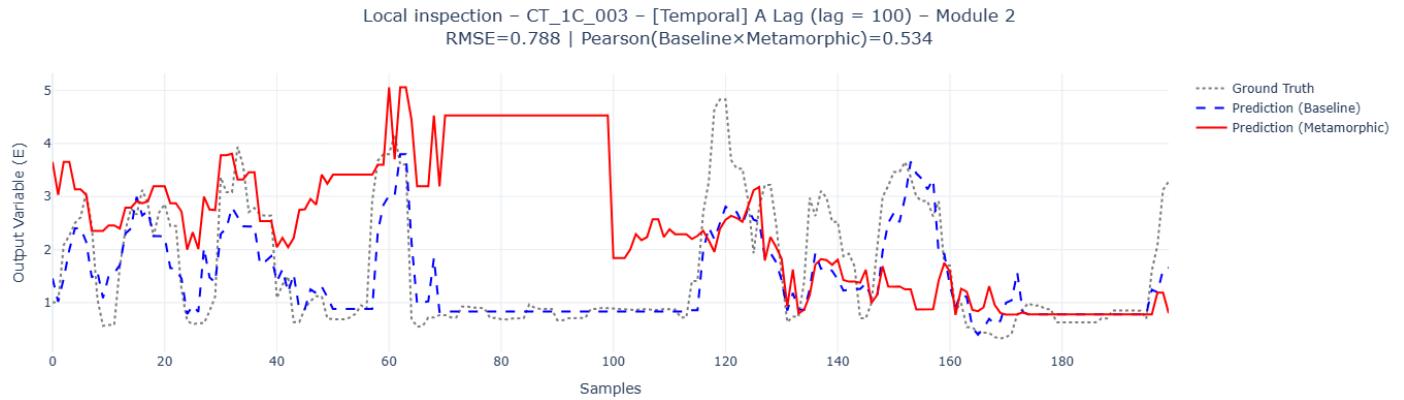
- RMSE (Baseline × Metamorphic Prediction) : 0.4105
- Pearson Correlation (Baseline × Metamorphic Prediction) : 0.573
- Pearson Correlation (Ground Truth × Metamorphic Prediction) : 0.500



### CT\_1C\_003 – Temporal Relation (A Lag = 100) – Module 2

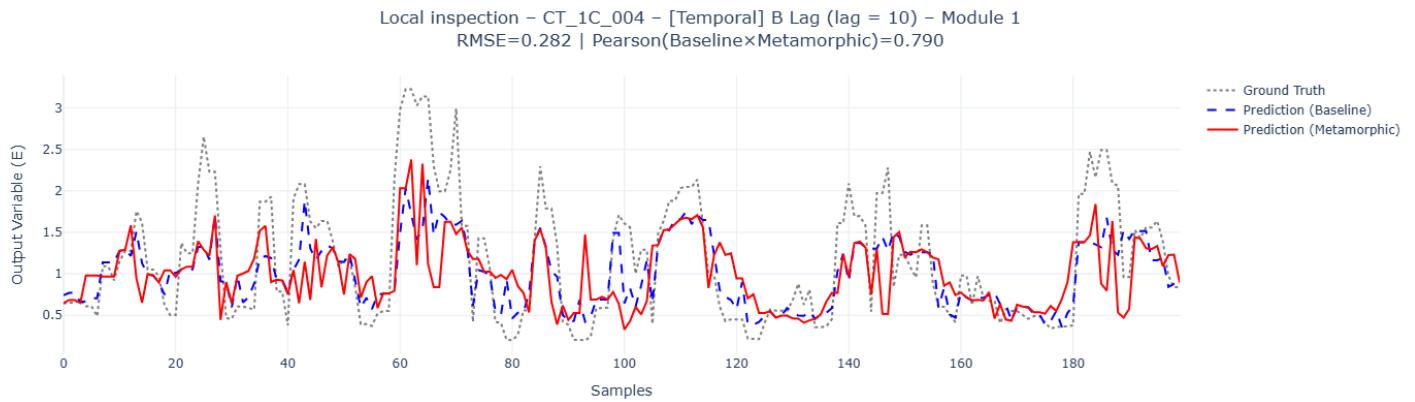
- RMSE (Baseline × Metamorphic Prediction) : 0.7877

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



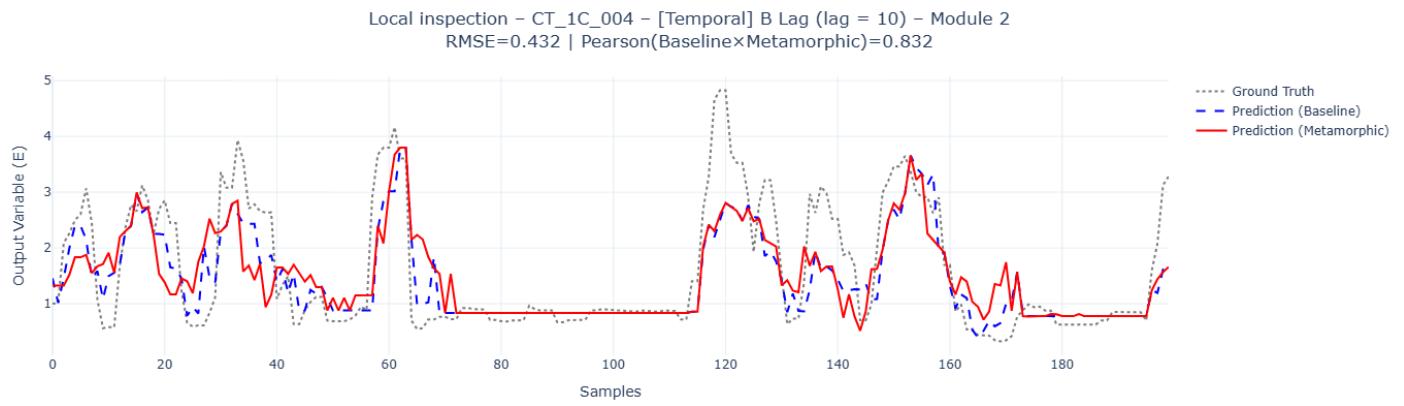
#### **CT\_1C\_004 – Temporal Relation (B Lag = 10) – Module 1**

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



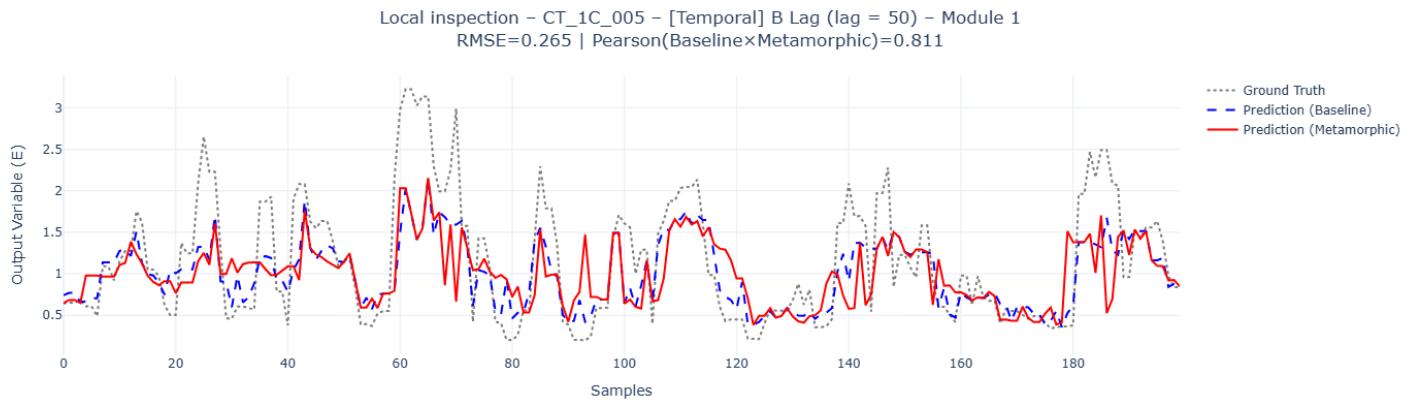
#### **CT\_1C\_004 – Temporal Relation (B Lag = 10) – Module 2**

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



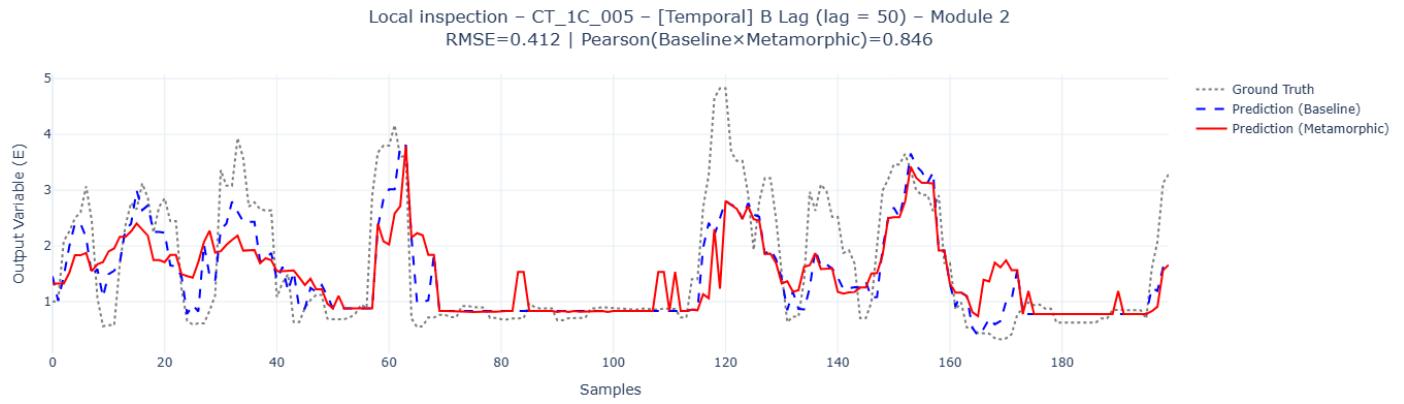
### CT\_1C\_005 – Temporal Relation (B Lag = 50) – Module 1

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



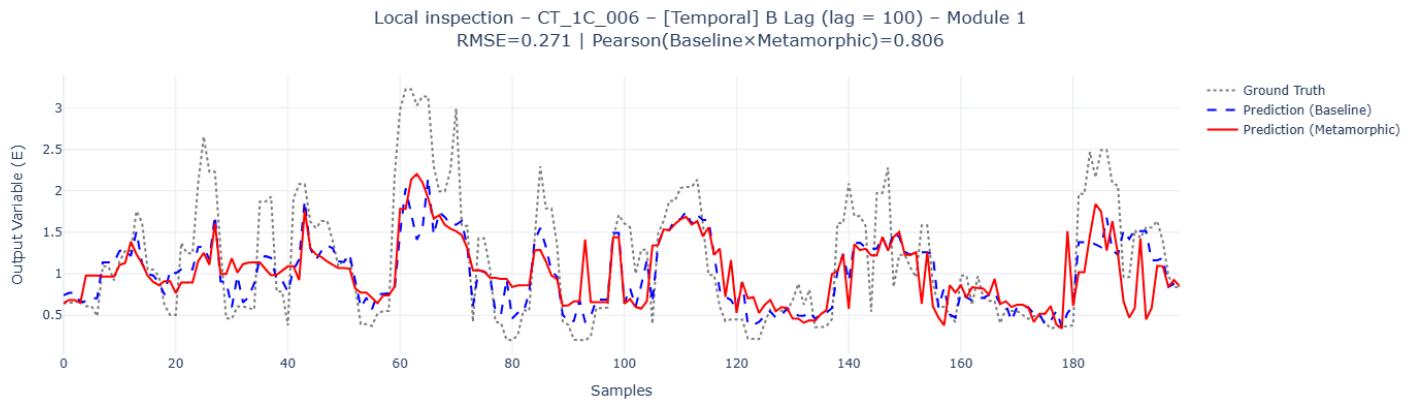
### CT\_1C\_005 – Temporal Relation (B Lag = 50) – Module 2

- 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

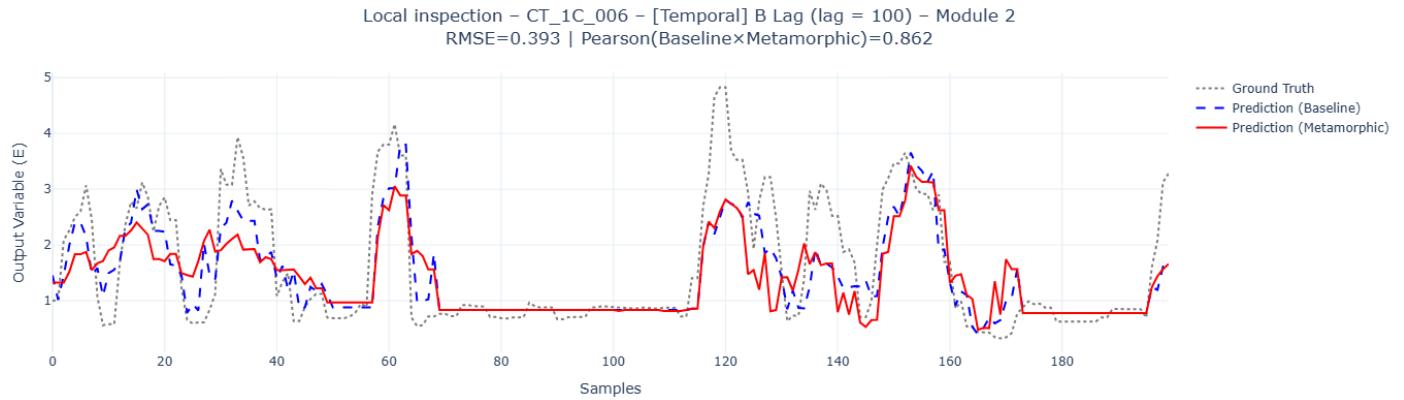
- RMSE (Baseline × Metamorphic Prediction) : 0.2710
- Pearson Correlation (Baseline × Metamorphic Prediction) : 0.806
- Pearson Correlation (Ground Truth × Metamorphic Prediction) : 0.692



### CT\_1C\_006 – Temporal Relation (B Lag = 100) – Module 2

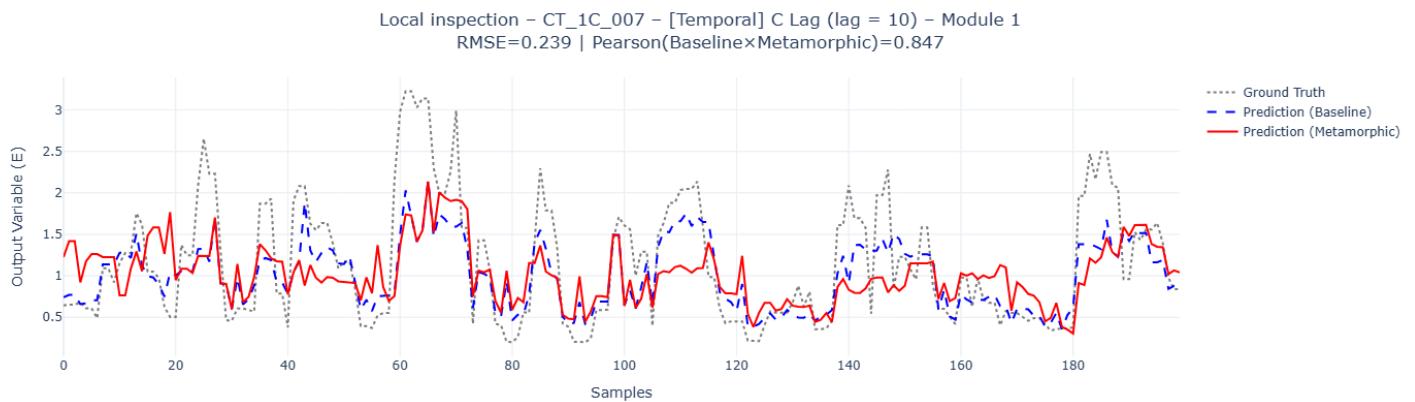
- RMSE (Baseline × Metamorphic Prediction) : 0.3927

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



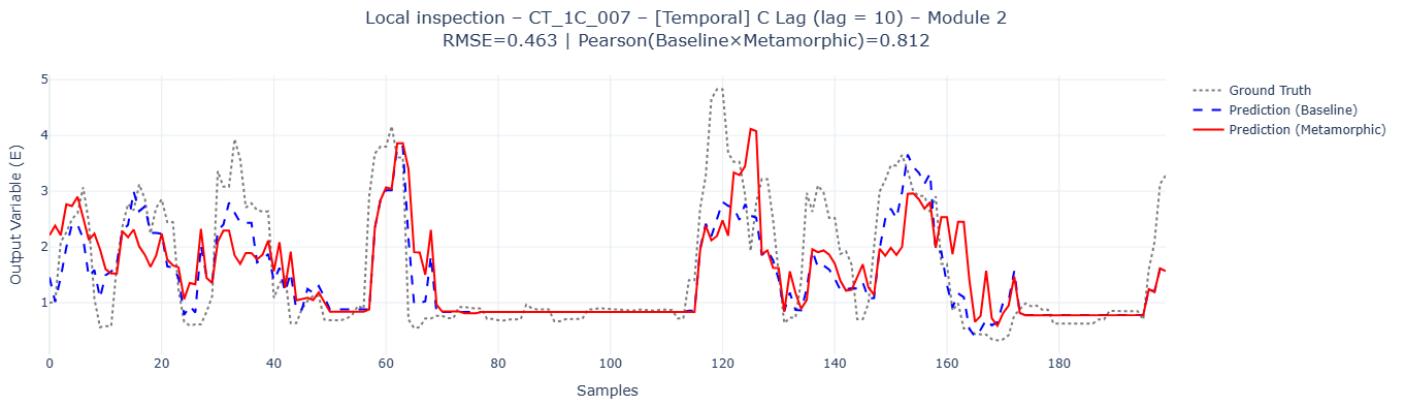
### **CT\_1C\_007 – Temporal Relation (C Lag = 10) – Module 1**

- RMSE (Baseline × Metamorphic Prediction) : 0.2395
- Pearson Correlation (Baseline × Metamorphic Prediction) : 0.847
- Pearson Correlation (Ground Truth × Metamorphic Prediction) : 0.733



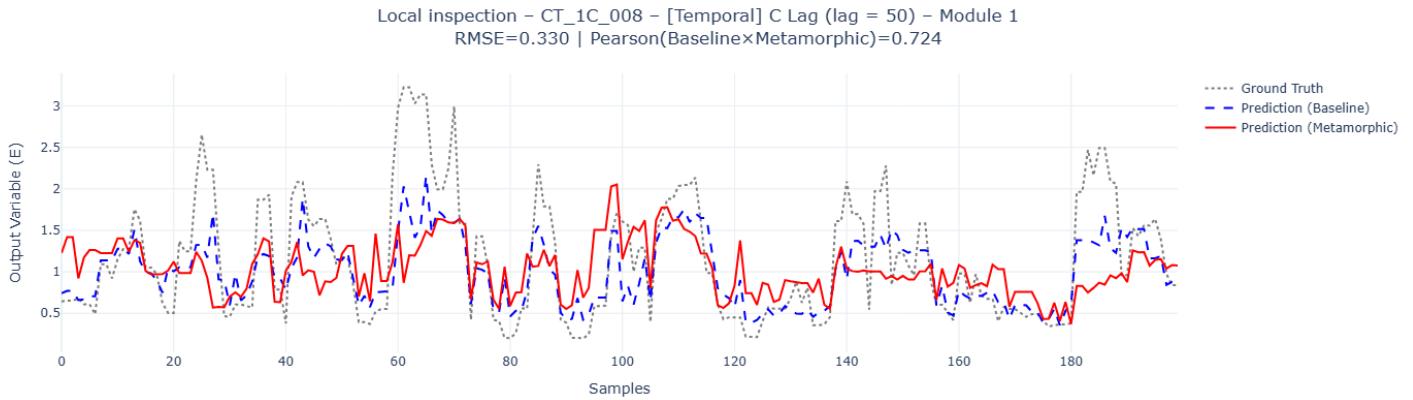
### **CT\_1C\_007 – Temporal Relation (C Lag = 10) – Module 2**

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



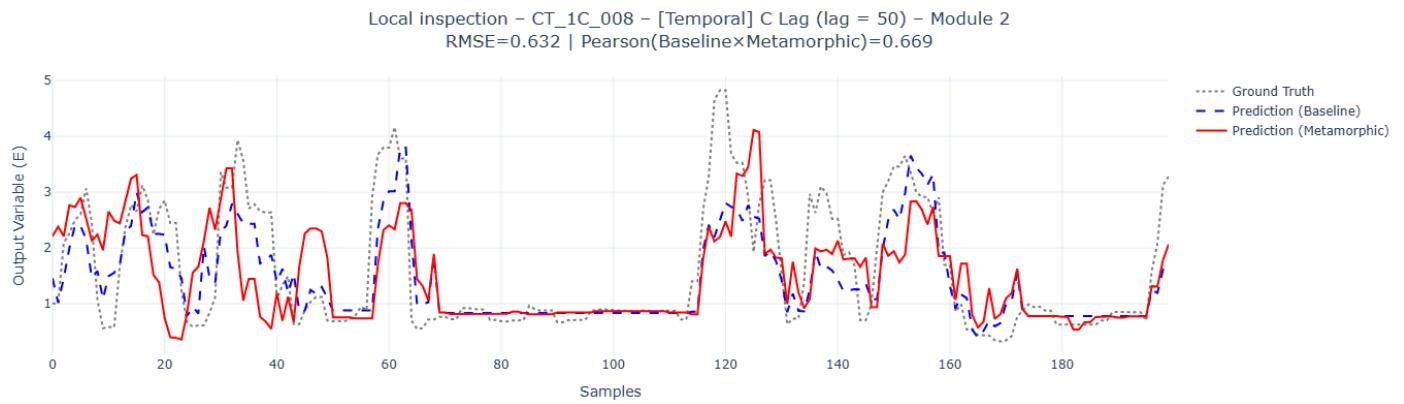
### CT\_1C\_008 – Temporal Relation (C Lag = 50) – Module 1

- RMSE (Baseline × Metamorphic Prediction): 0.3299
- Pearson Correlation (Baseline × Metamorphic Prediction): 0.724
- Pearson Correlation (Ground Truth × Metamorphic Prediction): 0.649



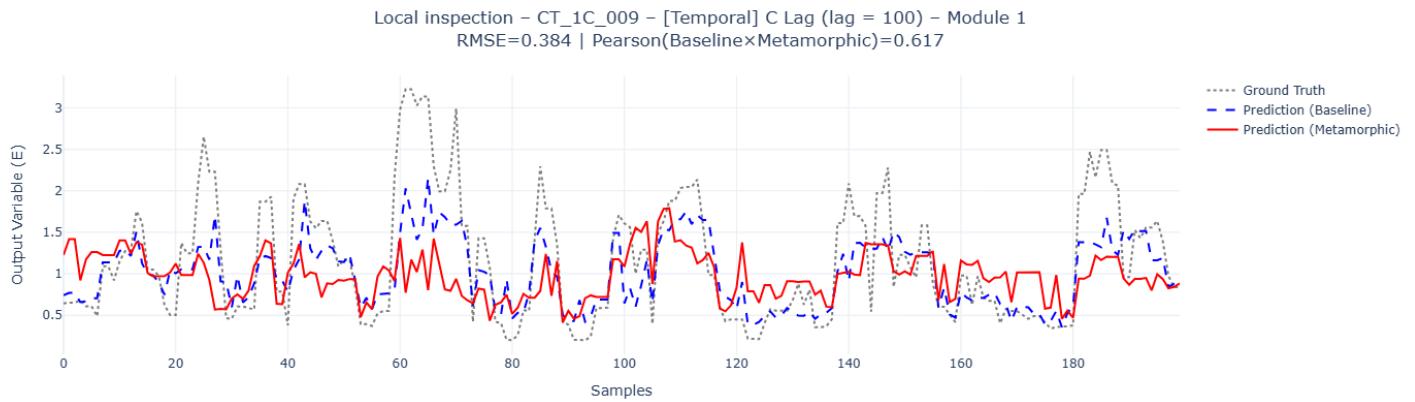
### CT\_1C\_008 – Temporal Relation (C Lag = 50) – Module 2

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



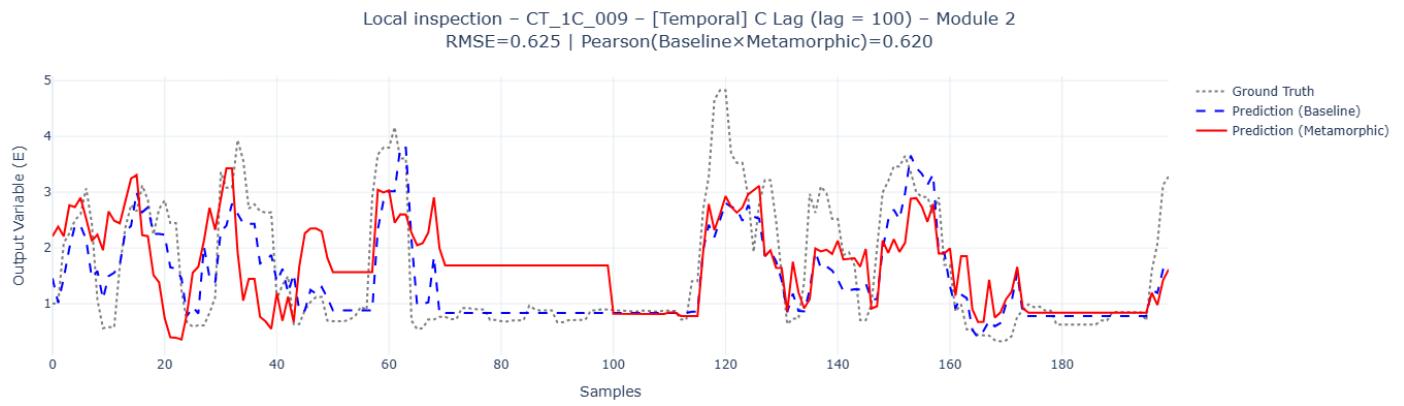
### **CT\_1C\_009 – Temporal Relation (C Lag = 100) – Module 1**

- RMSE (Baseline × Metamorphic Prediction) : 0.3836
- Pearson Correlation (Baseline × Metamorphic Prediction) : 0.617
- Pearson Correlation (Ground Truth × Metamorphic Prediction) : 0.567



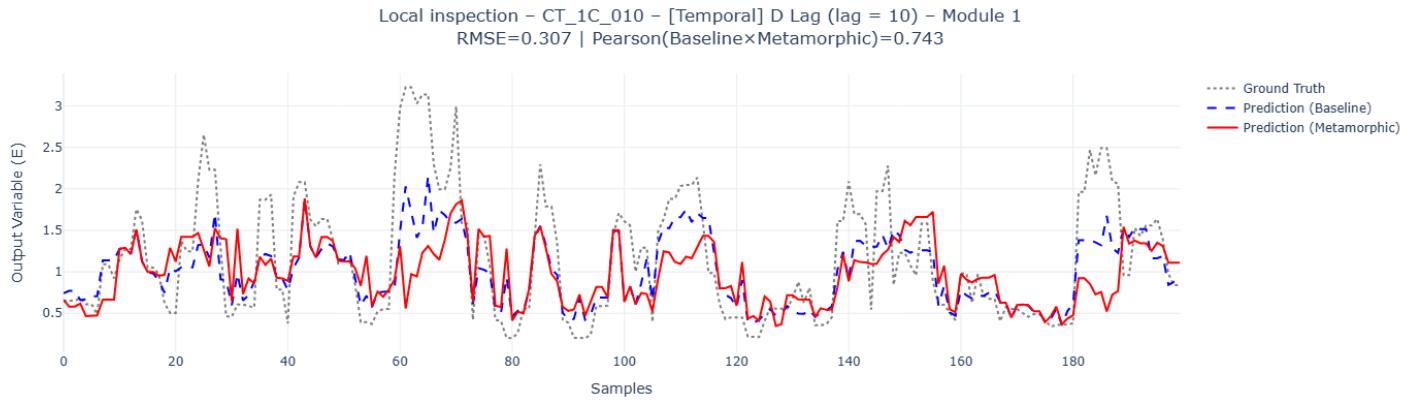
### **CT\_1C\_009 – Temporal Relation (C Lag = 100) – Module 2**

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



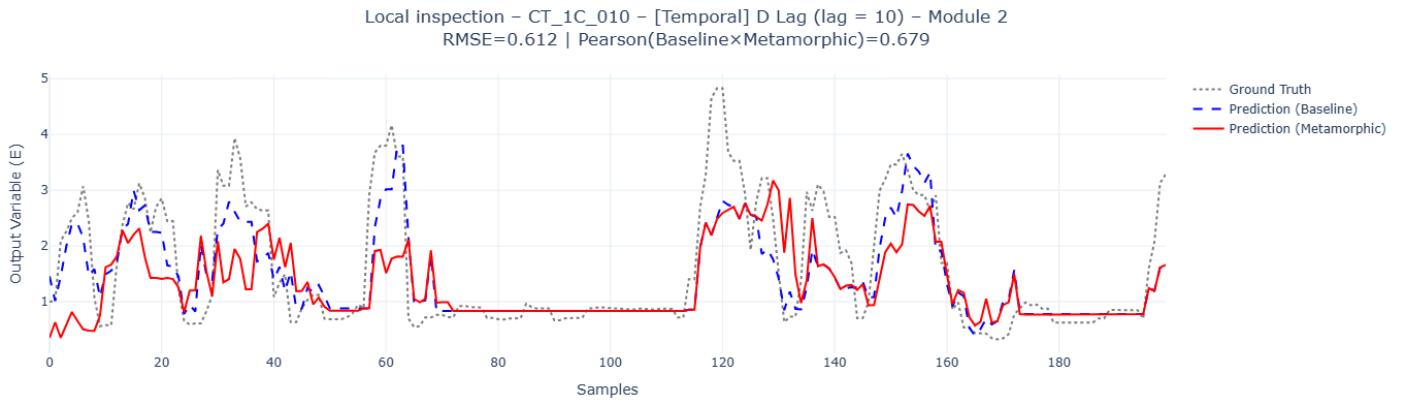
### **CT\_1C\_010 – Temporal Relation (D Lag = 10) – Module 1**

- RMSE (Baseline × Metamorphic Prediction) : 0.3066
- Pearson Correlation (Baseline × Metamorphic Prediction) : 0.743
- Pearson Correlation (Ground Truth × Metamorphic Prediction) : 0.589



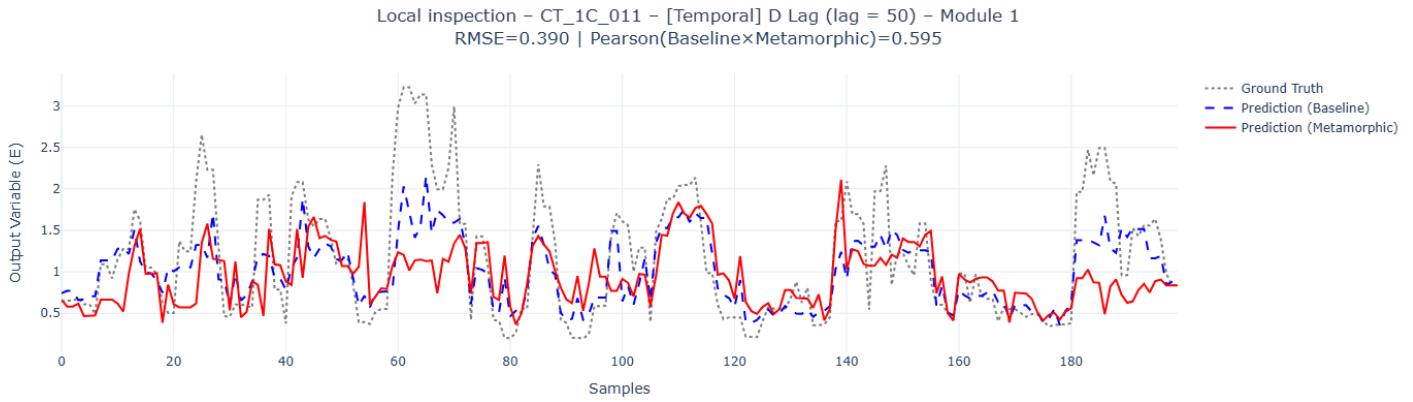
### **CT\_1C\_010 – Temporal Relation (D Lag = 10) – Module 2**

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



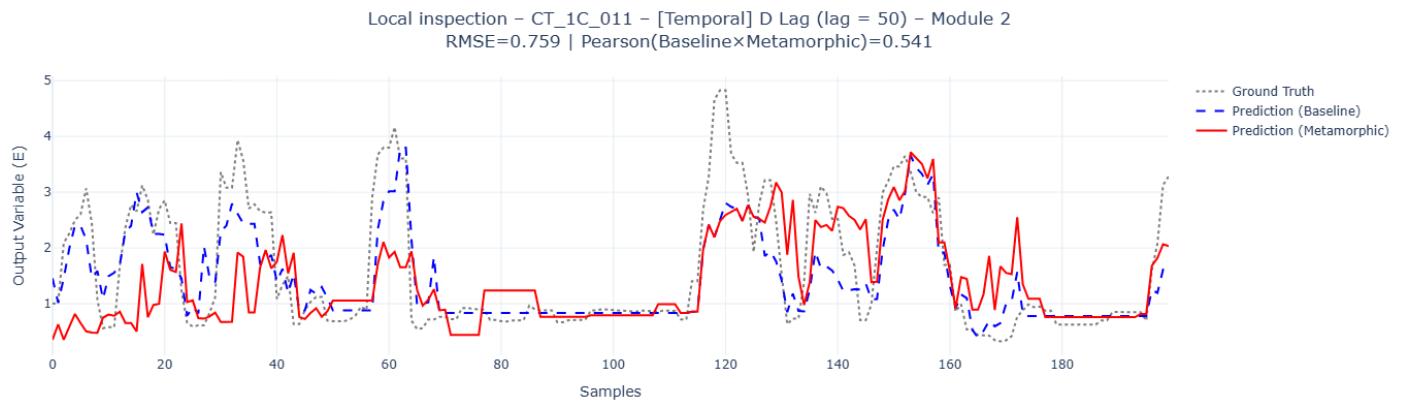
### CT\_1C\_011 – Temporal Relation (D Lag = 50) – Module 1

- RMSE (Baseline × Metamorphic Prediction) : 0.3898
- Pearson Correlation (Baseline × Metamorphic Prediction) : 0.595
- Pearson Correlation (Ground Truth × Metamorphic Prediction) : 0.493



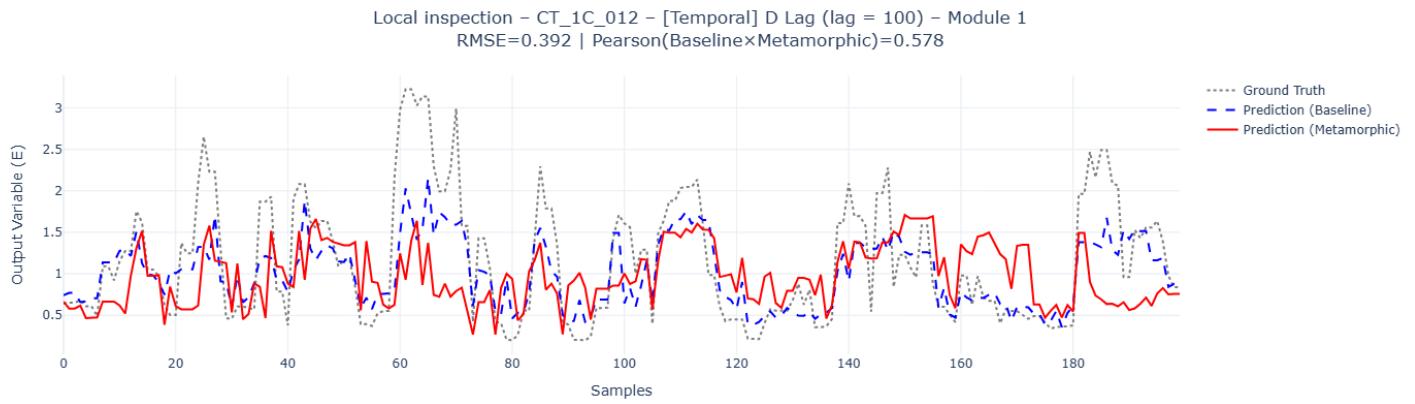
### CT\_1C\_011 – Temporal Relation (D Lag = 50) – Module 2

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



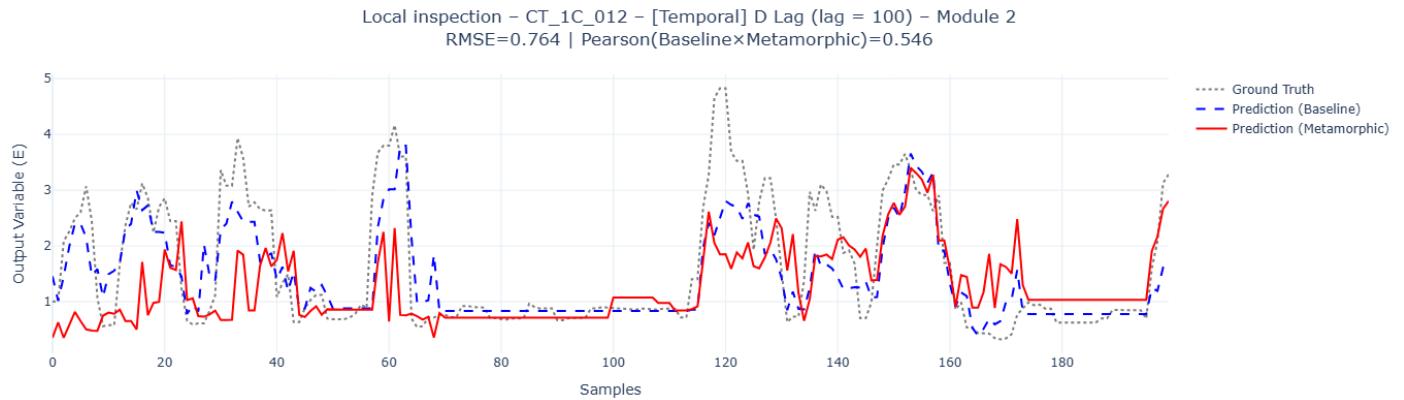
### CT\_1C\_012 – Temporal Relation (D Lag = 100) – Module 1

- 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.

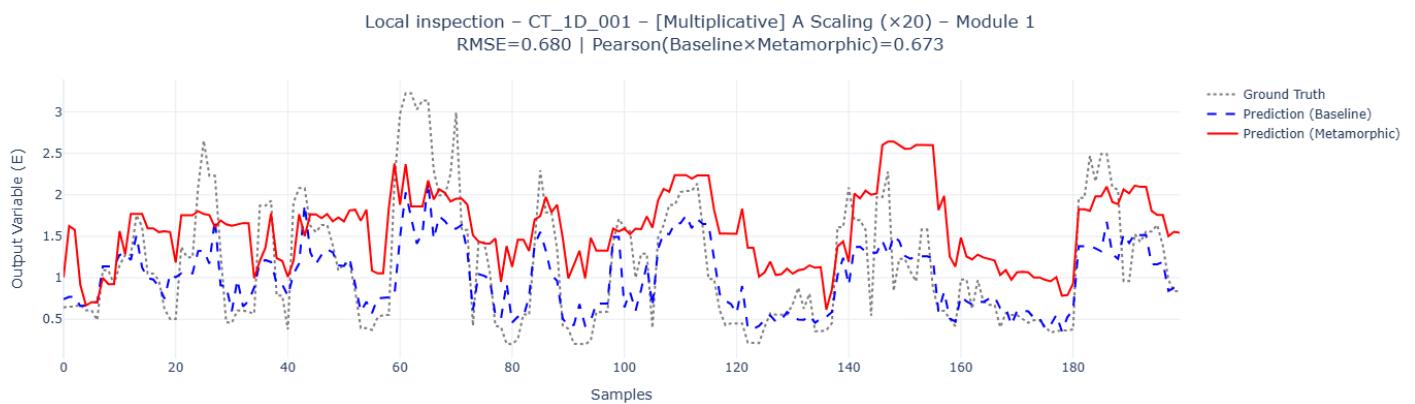
Each test case multiplies one input variable by a fixed factor ( $\times 20$ ), while the remaining variables preserve their original values and structure.

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

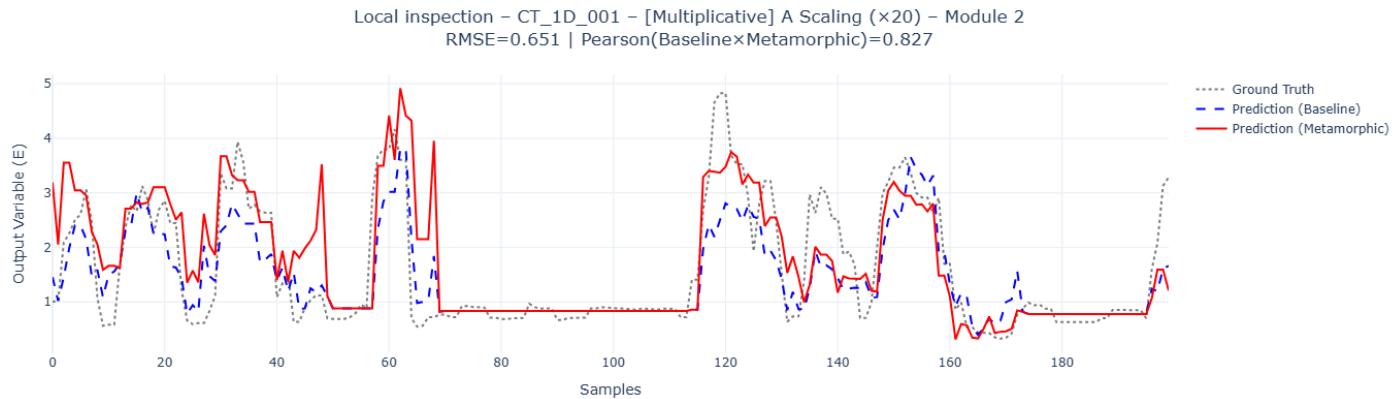
### CT\_1D\_001 – Multiplicative Relation (A ×20) – Module 1

- 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**

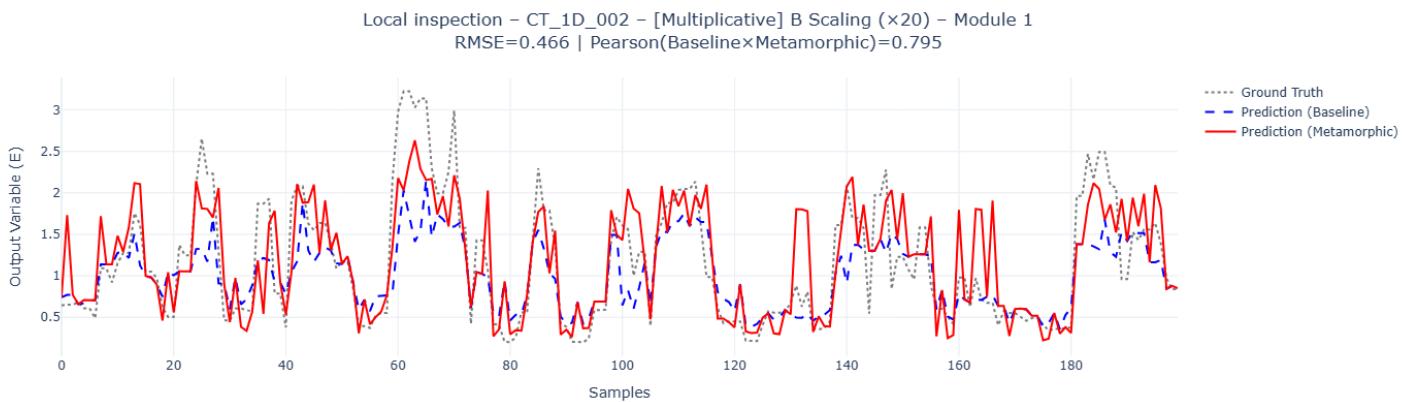
- RMSE (Baseline × Metamorphic Prediction): 0.6509
- Pearson Correlation (Baseline × Metamorphic Prediction): 0.827
- Pearson Correlation (Ground Truth × Metamorphic Prediction): 0.680



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## **CT\_1D\_002 – Multiplicative Relation (B ×20) – Module 1**

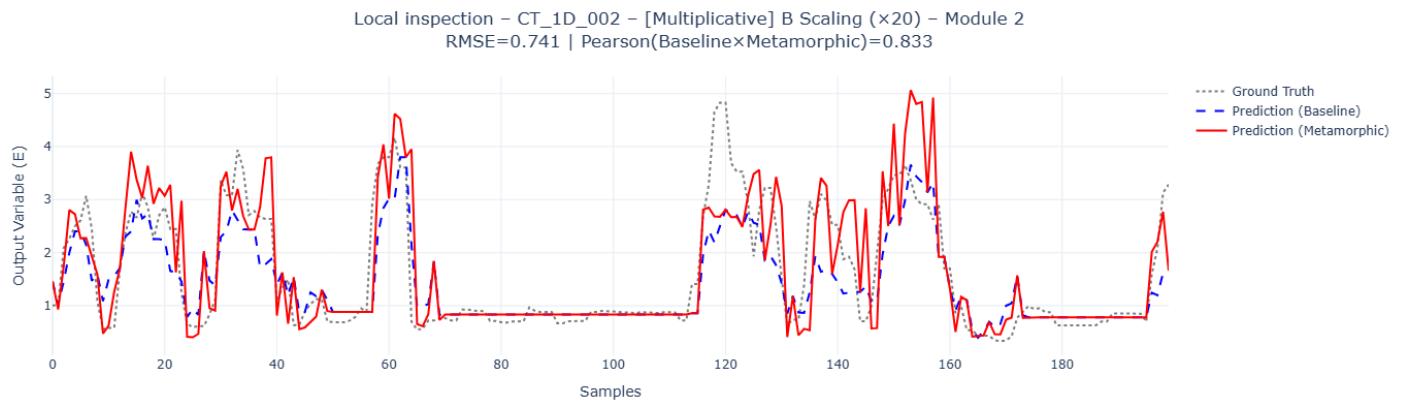
- RMSE (Baseline × Metamorphic Prediction): 0.4663
- Pearson Correlation (Baseline × Metamorphic Prediction): 0.795
- Pearson Correlation (Ground Truth × Metamorphic Prediction): 0.780



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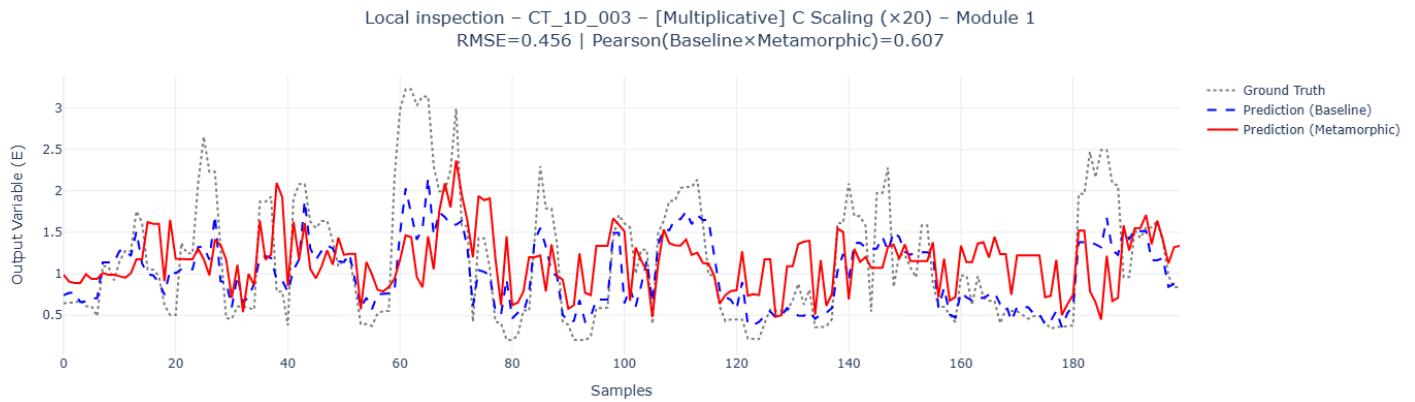
## **CT\_1D\_002 – Multiplicative Relation (B ×20) – Module 2**

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



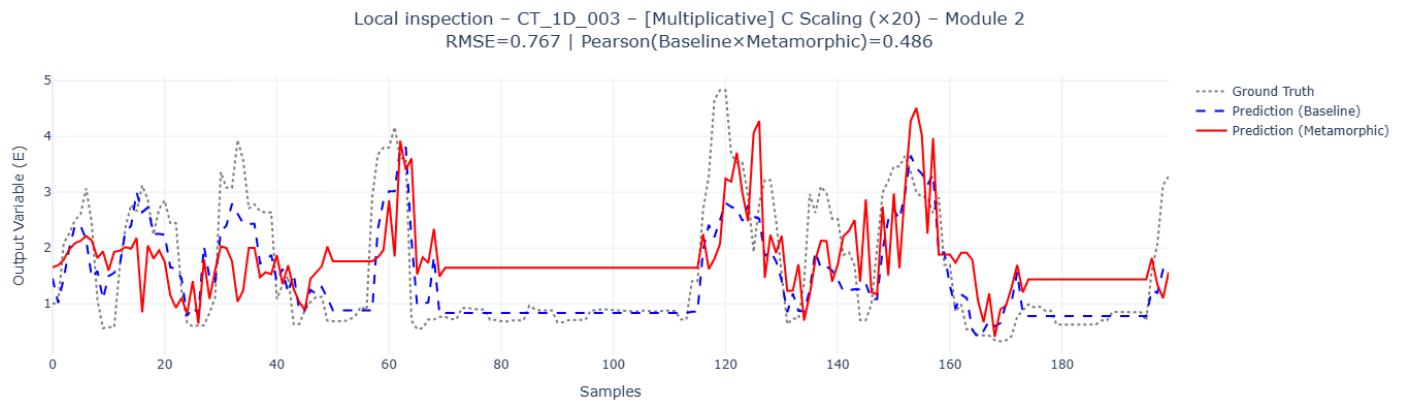
### CT\_1D\_003 – Multiplicative Relation (C $\times 20$ ) – Module 1

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



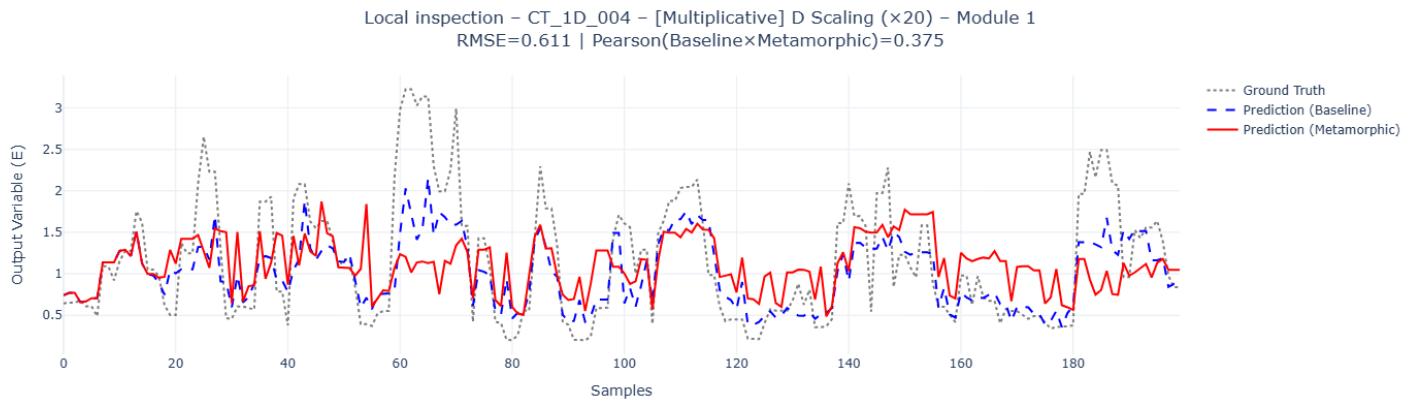
### CT\_1D\_003 – Multiplicative Relation (C $\times 20$ ) – Module 2

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



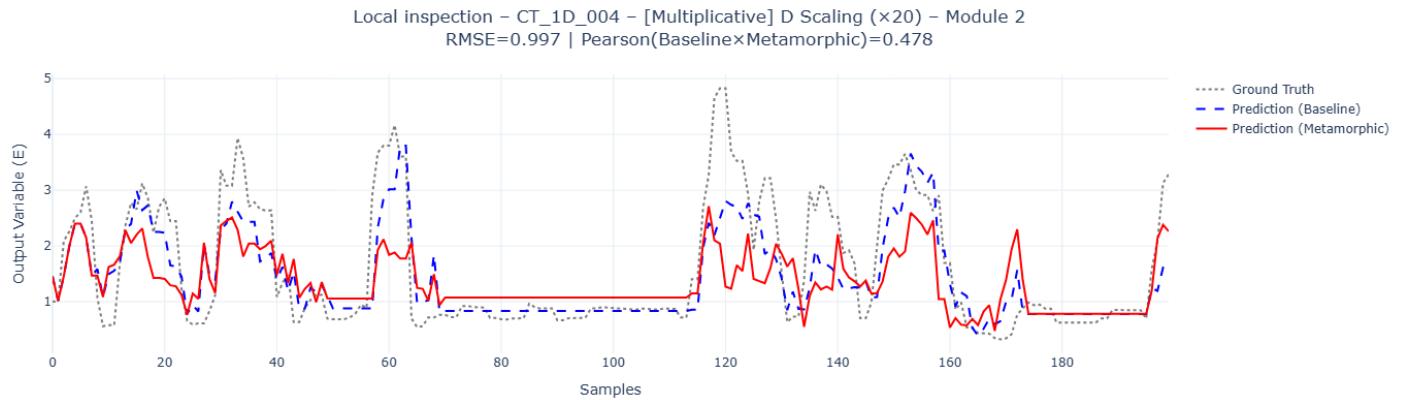
#### CT\_1D\_004 – Multiplicative Relation (D $\times 20$ ) – Module 1

- 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 $\times 20$ ) – 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.

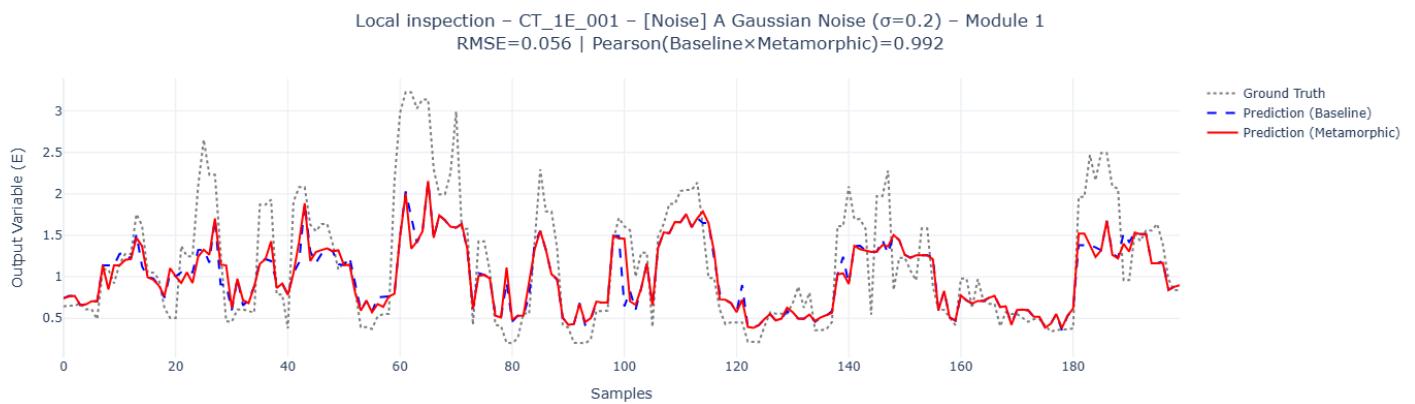
Each test case adds noise with moderate variance ( $\sigma = 0.2$ ) to one input variable, while preserving the structure, dimensionality, and temporal organization of the dataset.

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, $\sigma = 0.2$ ) – Module 1

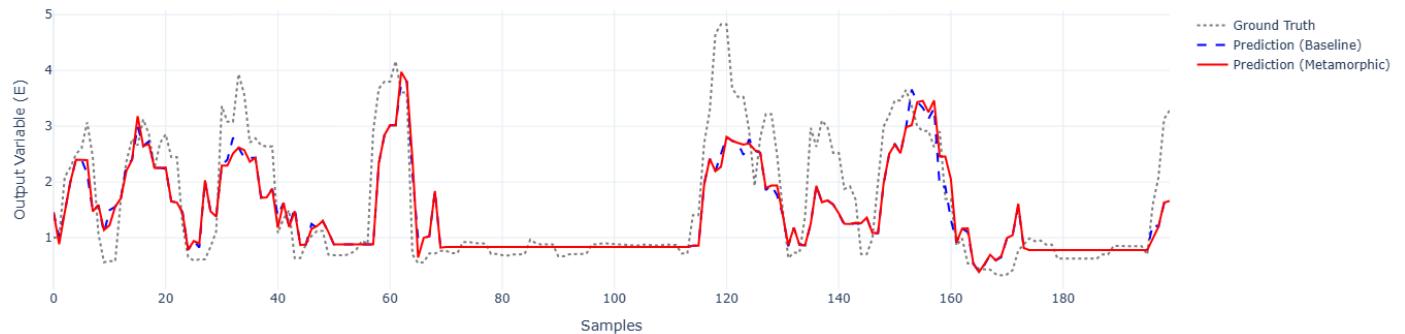
- RMSE (Baseline × Metamorphic Prediction) : 0.0565
- Pearson Correlation (Baseline × Metamorphic Prediction) : 0.992
- Pearson Correlation (Ground Truth × Metamorphic Prediction) : 0.815



**CT\_1E\_001 – Sustainable Relation (Gaussian Noise on A,  $\sigma = 0.2$ ) – Module 2**

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

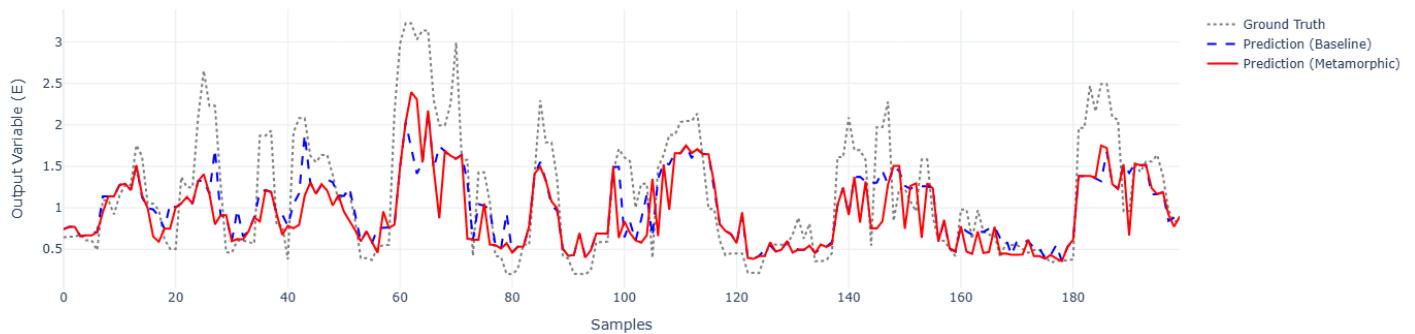
Local inspection – CT\_1E\_001 – [Noise] A Gaussian Noise ( $\sigma=0.2$ ) – Module 2  
RMSE=0.067 | Pearson(Baseline×Metamorphic)=0.996



**CT\_1E\_002 – Sustainable Relation (Gaussian Noise on B,  $\sigma = 0.2$ ) – Module 1**

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

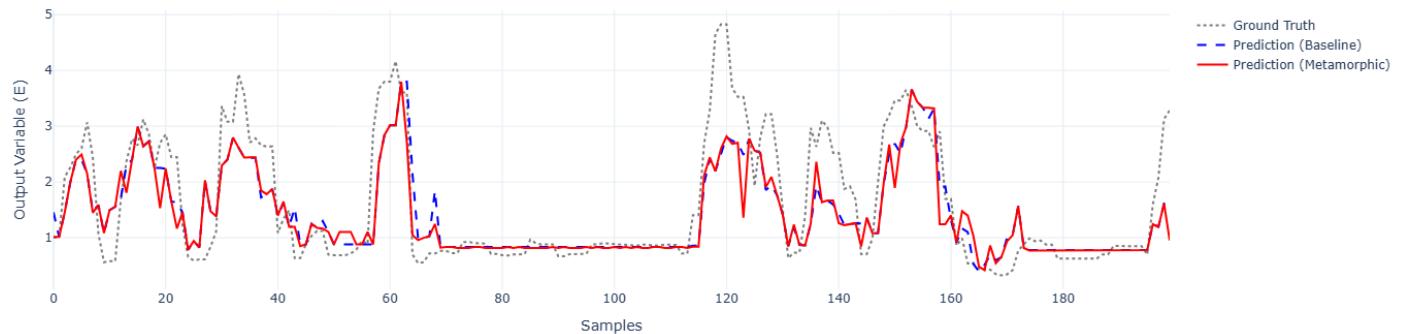
Local inspection – CT\_1E\_002 – [Noise] B Gaussian Noise ( $\sigma=0.2$ ) – Module 1  
RMSE=0.171 | Pearson(Baseline×Metamorphic)=0.928



**CT\_1E\_002 – Sustainable Relation (Gaussian Noise on B,  $\sigma = 0.2$ ) – Module 2**

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

Local inspection – CT\_1E\_002 – [Noise] B Gaussian Noise ( $\sigma=0.2$ ) – Module 2  
RMSE=0.234 | Pearson(Baseline×Metamorphic)=0.955

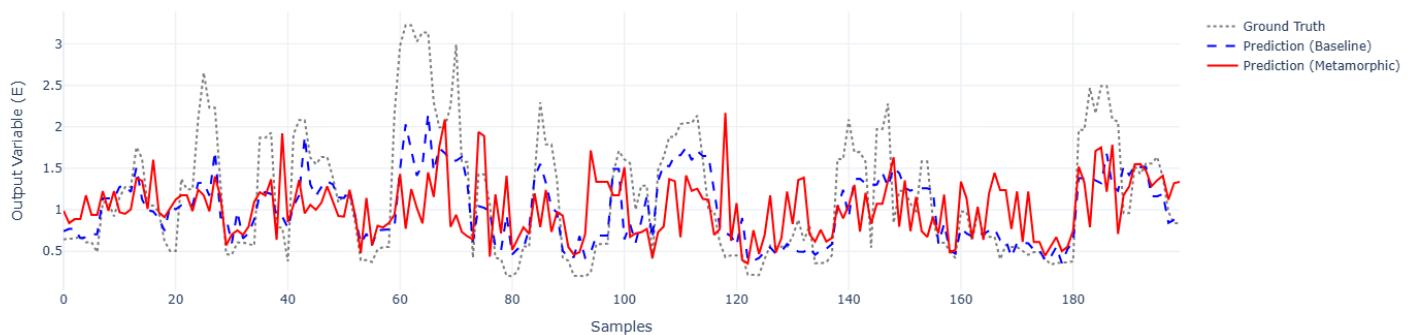


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**CT\_1E\_003 – Sustainable Relation (Gaussian Noise on C,  $\sigma = 0.2$ ) – Module 1**

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

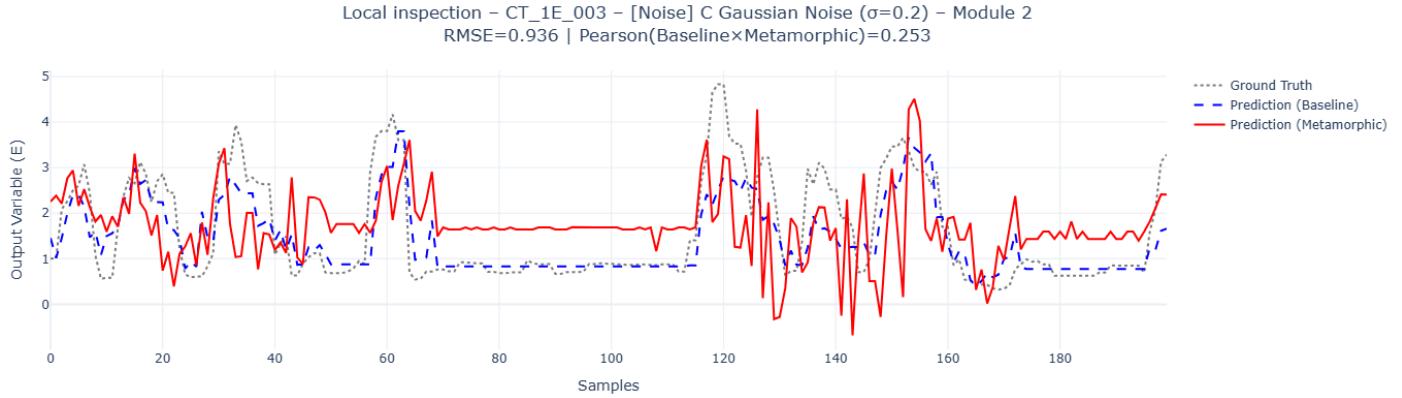
Local inspection – CT\_1E\_003 – [Noise] C Gaussian Noise ( $\sigma=0.2$ ) – Module 1  
RMSE=0.429 | Pearson(Baseline×Metamorphic)=0.506



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**CT\_1E\_003 – Sustainable Relation (Gaussian Noise on C,  $\sigma = 0.2$ ) – Module 2**

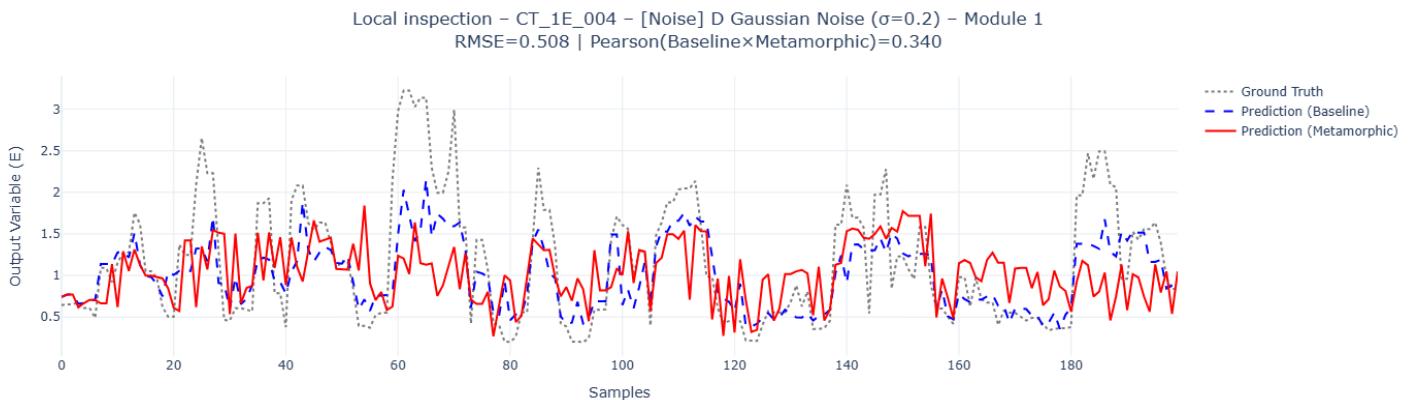
- RMSE (Baseline × Metamorphic Prediction): 0.9360
- Pearson Correlation (Baseline × Metamorphic Prediction): 0.253
- Pearson Correlation (Ground Truth × Metamorphic Prediction): 0.194



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**CT\_1E\_004 – Sustainable Relation (Gaussian Noise on D,  $\sigma = 0.2$ ) – Module 1**

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



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**CT\_1E\_004 – Sustainable Relation (Gaussian Noise on D,  $\sigma = 0.2$ ) –  
Module 2**

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

