Scenario 2A — Multiplicative Scaling of Kinematic Inputs

Metamorphic Relation Type: Multiplicative (M)

Description

This scenario evaluates the system’s causal coherence when kinematic input variables are scaled by fixed multiplicative factors.

Each test case applies a multiplicative transformation to one or more kinematic variables—Speed and Acceleration—while preserving the remaining inputs (Latitude and Longitude), the dataset structure, and temporal ordering.

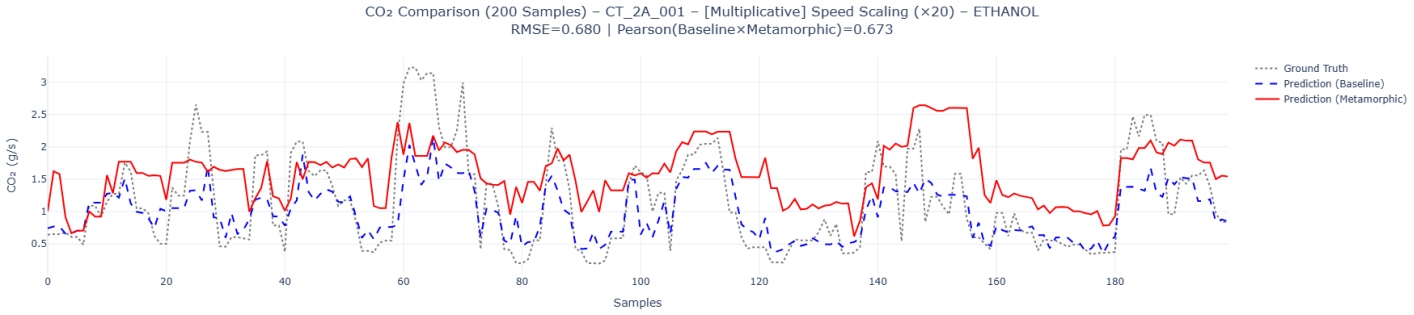
According to the Multiplicative (M) metamorphic relation, scaling input magnitudes is expected to induce proportional and coherent variations in the system output, without interrupting execution or violating internal consistency.

The resulting Metamorphic Prediction is compared against the Baseline Prediction using quantitative metrics and visual inspection.

Test Cases

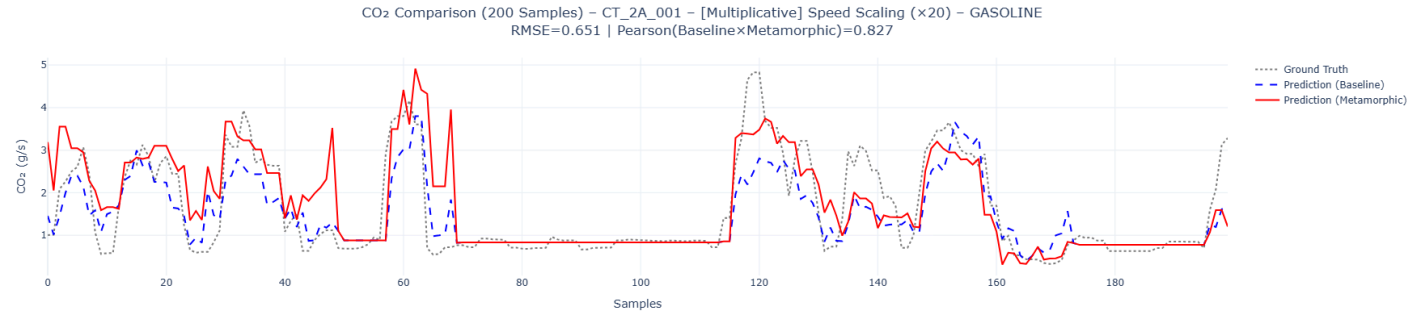
CT_2A_001 — Multiplicative Relation (Speed ×20) — Ethanol

- **RMSE (Baseline × Metamorphic Prediction):** 0.6804
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.673
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.575



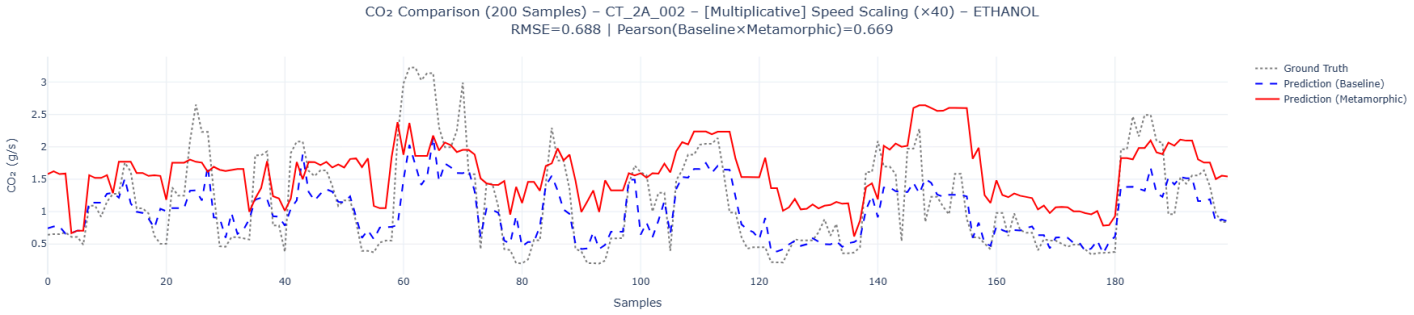
CT_2A_001 — Multiplicative Relation (Speed ×20) — Gasoline

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



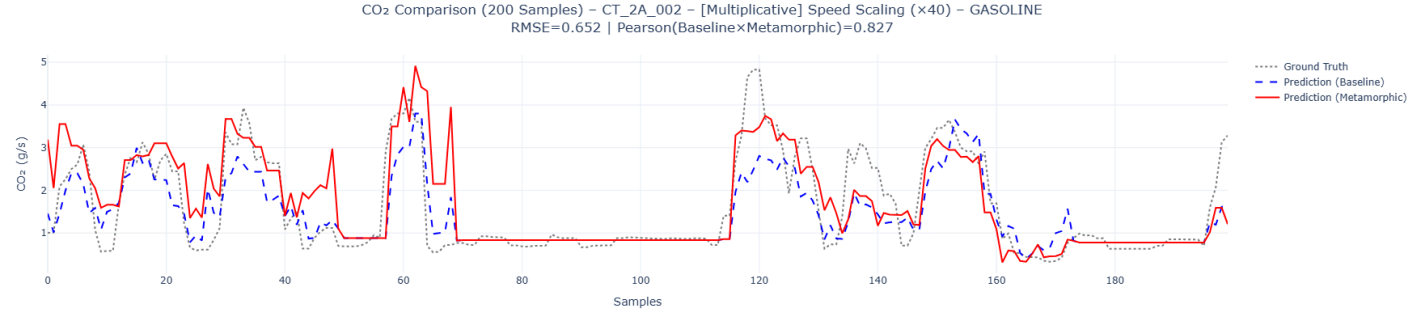
CT_2A_002 — Multiplicative Relation (Speed ×40) — Ethanol

- **RMSE (Baseline × Metamorphic Prediction):** 0.6885
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.669
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.571



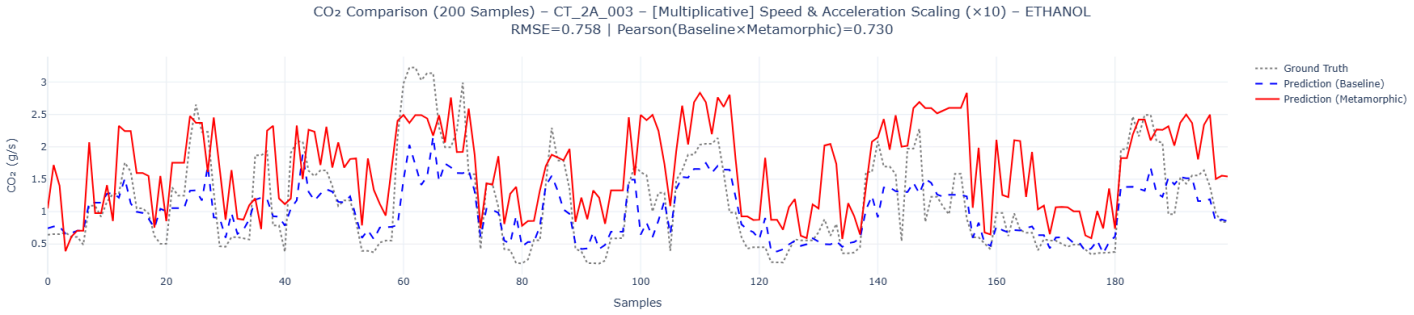
CT_2A_002 — Multiplicative Relation (Speed ×40) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 0.6519
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.827
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.681



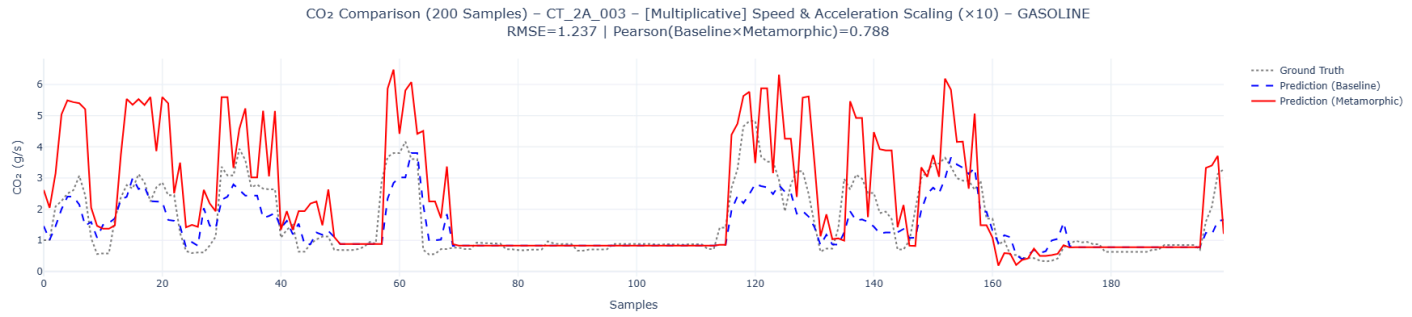
CT_2A_003 — Multiplicative Relation (Speed & Acceleration ×10) — Ethanol

- **RMSE (Baseline × Metamorphic Prediction):** 0.7584
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.730
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.701



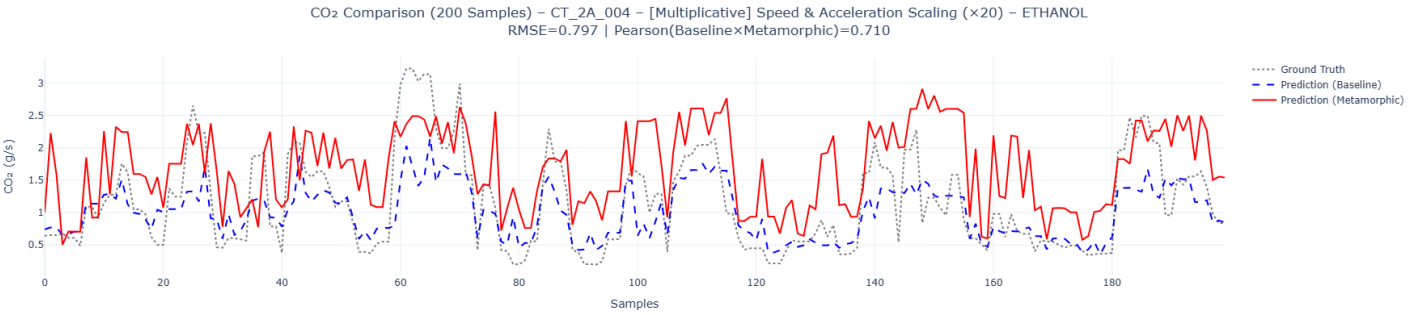
CT_2A_003 — Multiplicative Relation (Speed & Acceleration ×10) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 1.2370
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.788
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.751



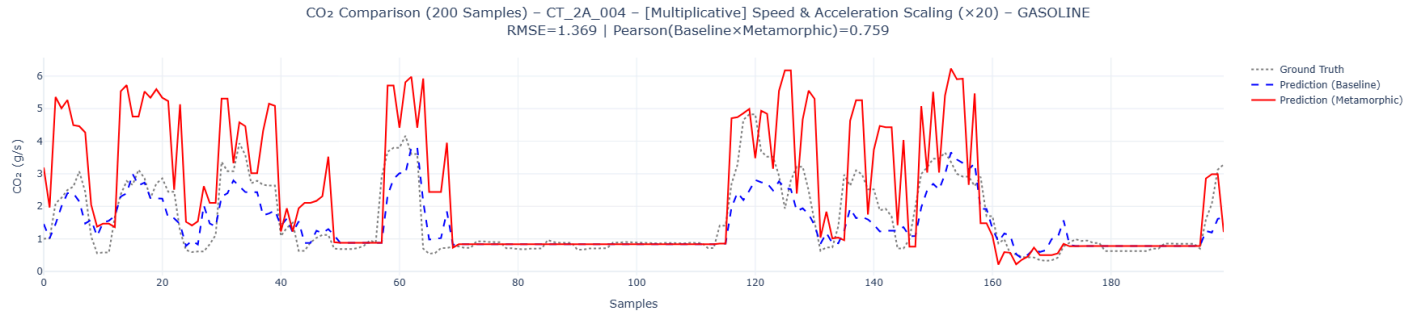
CT_2A_004 — Multiplicative Relation (Speed & Acceleration ×20) — Ethanol

- **RMSE (Baseline × Metamorphic Prediction):** 0.7969
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.710
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.665



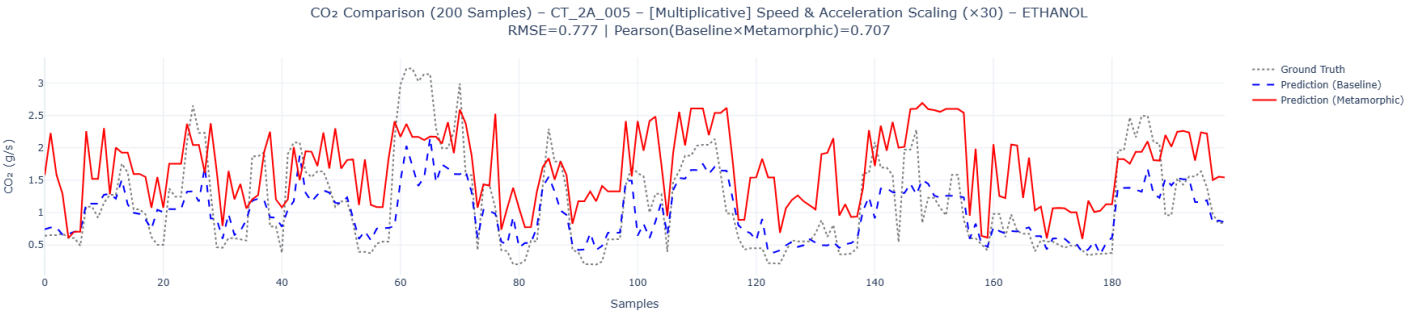
CT_2A_004 — Multiplicative Relation (Speed & Acceleration ×20) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 1.3692
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.759
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.711



CT_2A_005 — Multiplicative Relation (Speed & Acceleration ×30) — Ethanol

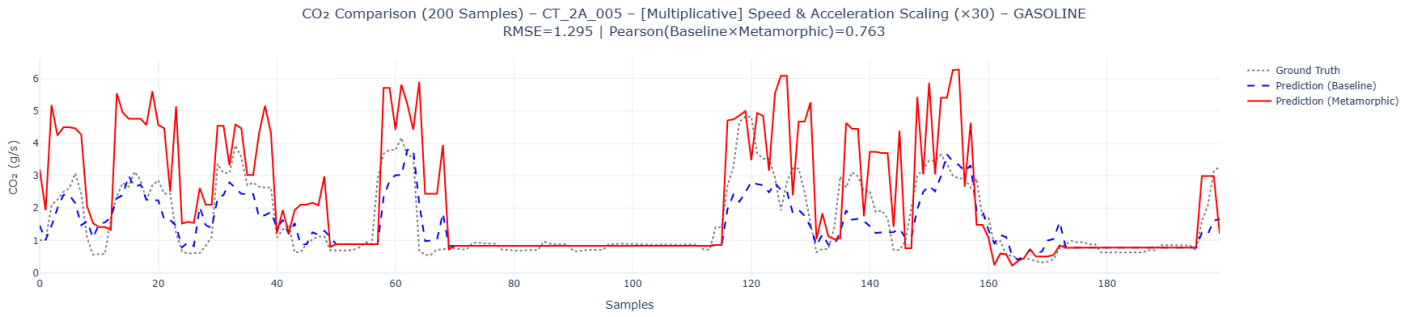
- **RMSE (Baseline × Metamorphic Prediction):** 0.7767
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.707
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.649



CT_2A_005 — Multiplicative Relation (Speed & Acceleration ×30) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 1.2955
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.763

- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.712



Scenario 2B — Additive Translation of Spatial Coordinates

Metamorphic Relation Type: Additive (A)

Description

This scenario evaluates the system's causal and spatial coherence when constant additive translations are applied to spatial input variables.

Each test case applies a fixed additive offset to the spatial coordinates (Latitude and Longitude), while preserving all other input variables, the temporal structure, and the dynamic relationships among samples.

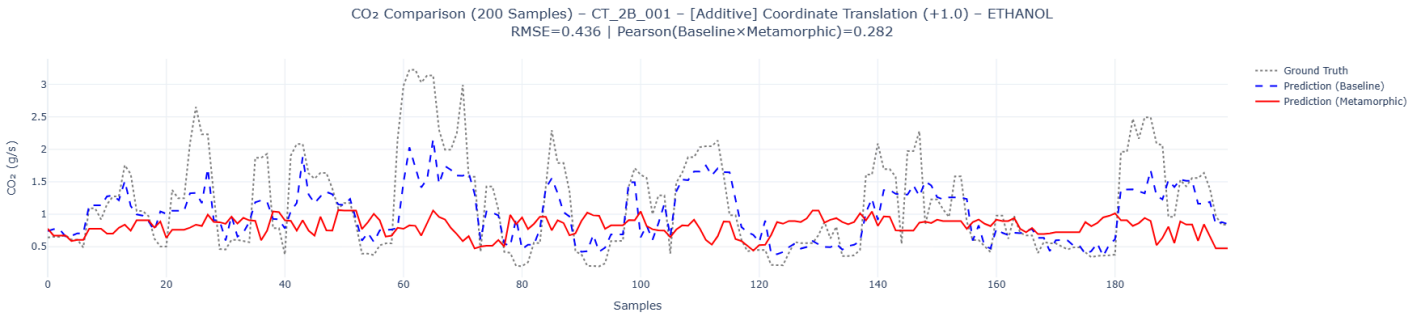
According to the Additive (A) metamorphic relation, spatial translations that do not alter relative positions or motion dynamics are expected to produce minimal or structurally consistent variations in the system output. Significant deviations may indicate sensitivity to absolute spatial positioning rather than relative spatial relationships.

The resulting Metamorphic Prediction is compared against the Baseline Prediction using quantitative metrics and visual inspection.

Test Cases

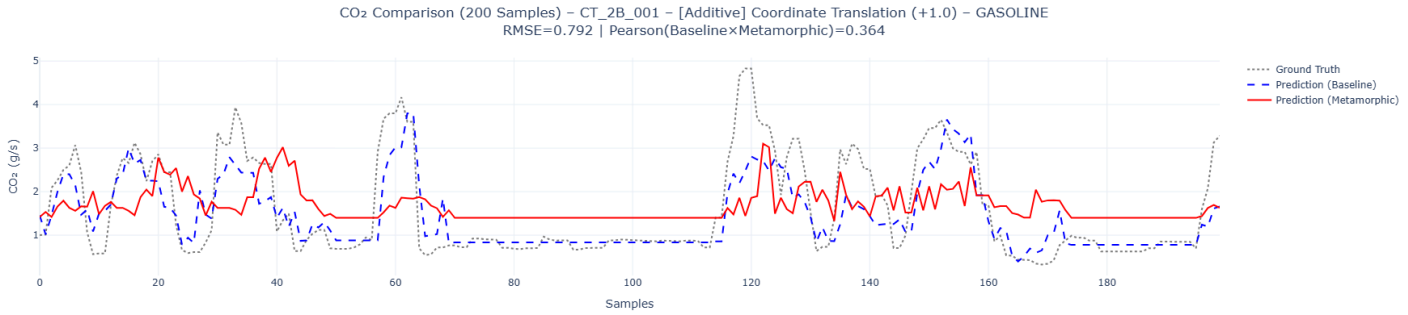
CT_2B_001 — Additive Relation (Coordinate Translation +1.0) — Ethanol

- **RMSE (Baseline × Metamorphic Prediction):** 0.4360
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.282
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.231



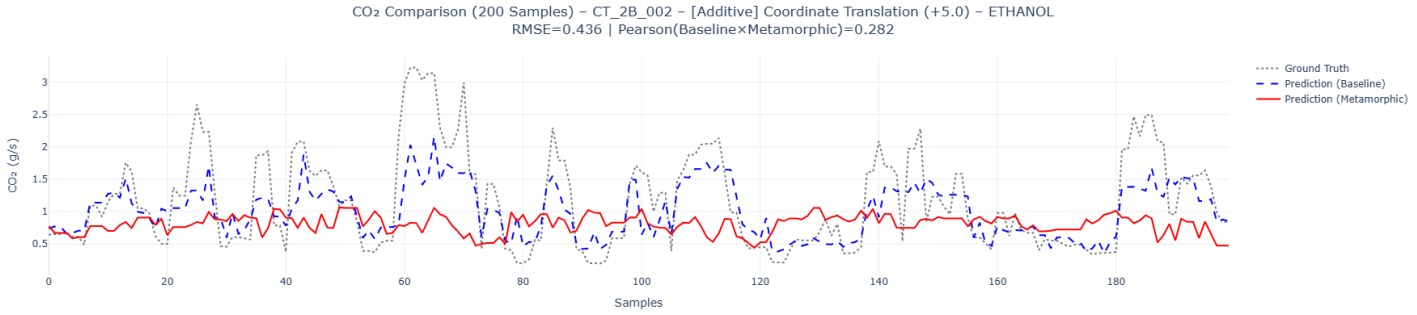
CT_2B_001 — Additive Relation (Coordinate Translation +1.0) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 0.7920
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.364
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.293



CT_2B_002 — Additive Relation (Coordinate Translation +5.0) — Ethanol

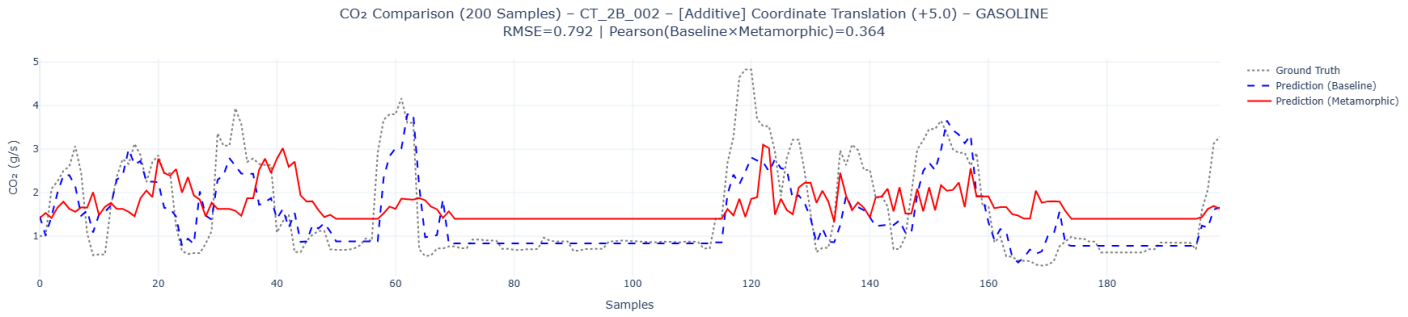
- **RMSE (Baseline × Metamorphic Prediction):** 0.4360
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.282
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.231



CT_2B_002 — Additive Relation (Coordinate Translation +5.0) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 0.7920
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.364

- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.293



Scenario 2C — Directional Inversion of Dynamic Input

Metamorphic Relation Type: Inversive (IV)

Description

This scenario evaluates the system's causal coherence when the direction of a dynamic input variable is inverted.

The test case applies a sign inversion to the Acceleration variable, transforming positive values into negative ones and vice versa, while preserving the magnitude, temporal structure, and all remaining input variables.

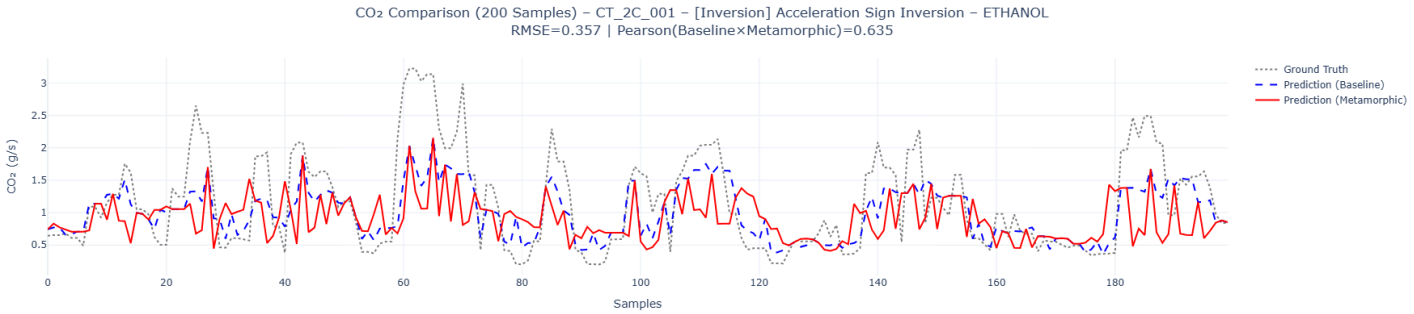
According to the Inversive (IV) metamorphic relation, directional inversion is expected to induce perceptible and coherent changes in the system output, reflecting sensitivity to directional dynamics without causing execution failures or structural inconsistencies.

The resulting Metamorphic Prediction is compared against the Baseline Prediction using quantitative metrics and visual inspection.

Test Cases

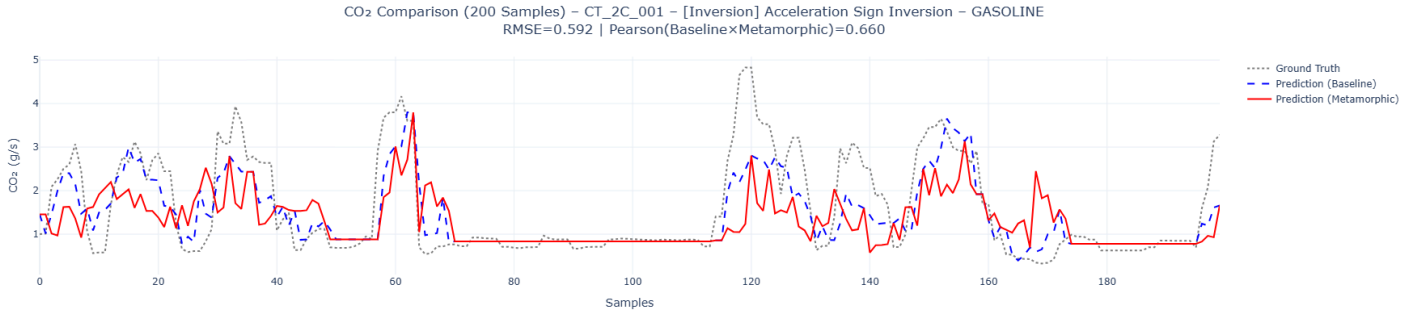
CT_2C_001 — Inversive Relation (Acceleration Sign Inversion) — Ethanol

- **RMSE (Baseline × Metamorphic Prediction):** 0.3569
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.635
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.446



CT_2C_001 — Inversive Relation (Acceleration Sign Inversion) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 0.5916
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.660
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.443



Scenario 2D — Temporal Reordering of Speed Signal

Metamorphic Relation Type: Permutative (P)
Description

This scenario evaluates the system's sensitivity to temporal reordering applied to a single kinematic input variable.

Each test case introduces a temporal lag to the Speed signal, shifting its samples forward in time while preserving the original values, dataset structure, and all remaining input variables.

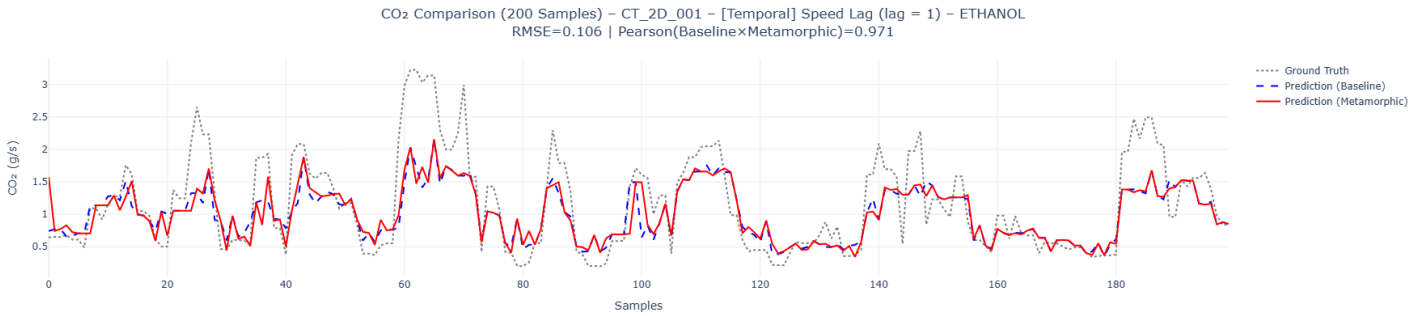
According to the Permutative (P) metamorphic relation, reordering samples without modifying their individual values is expected to produce progressive and coherent variations in the system output as the temporal displacement increases, without interrupting execution.

The resulting Metamorphic Prediction is compared against the Baseline Prediction using quantitative metrics and visual inspection.

Test Cases

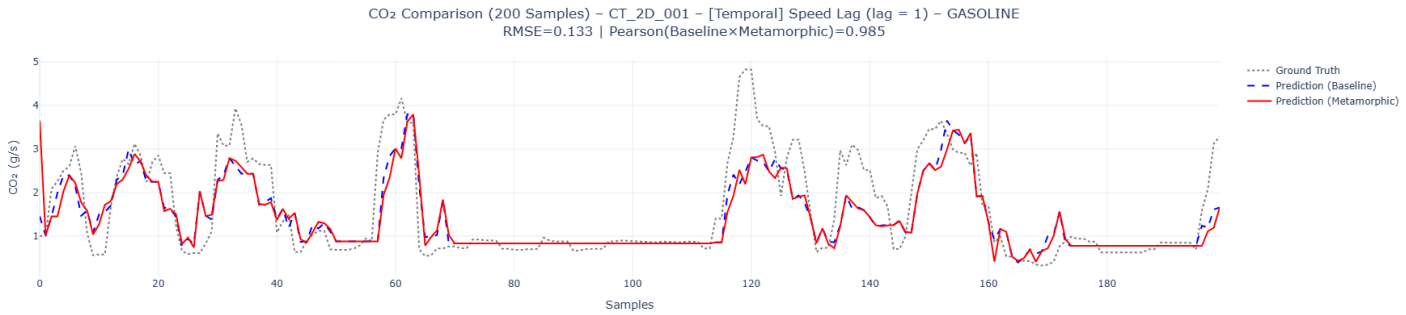
CT_2D_001 — Permutative Relation (Speed Lag = 1) — Ethanol

- **RMSE (Baseline × Metamorphic Prediction):** 0.1062
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.971
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.810



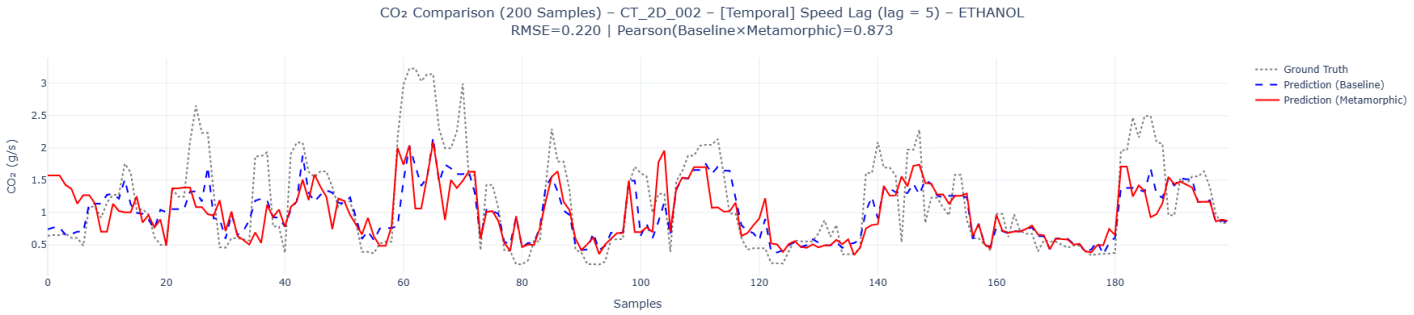
CT_2D_001 — Permutative Relation (Speed Lag = 1) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 0.1331
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.985
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.795



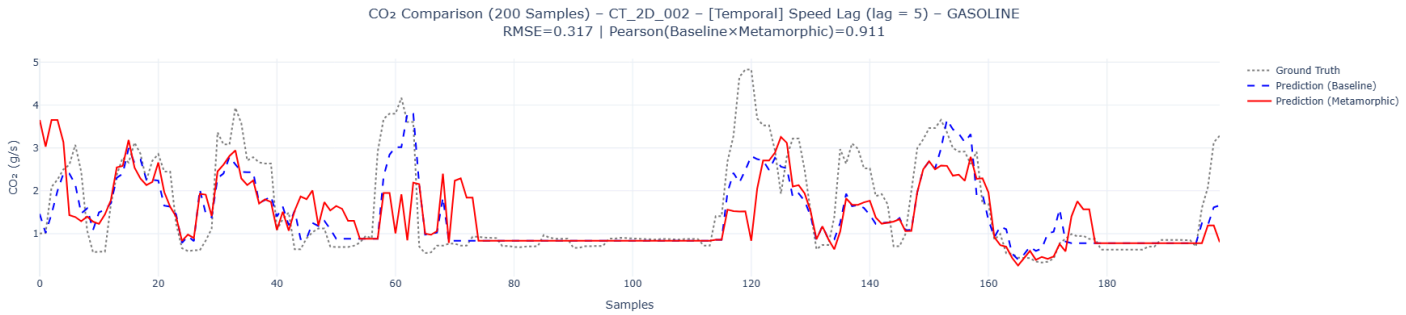
CT_2D_002 — Permutative Relation (Speed Lag = 5) — Ethanol

- **RMSE (Baseline × Metamorphic Prediction):** 0.2196
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.873
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.719



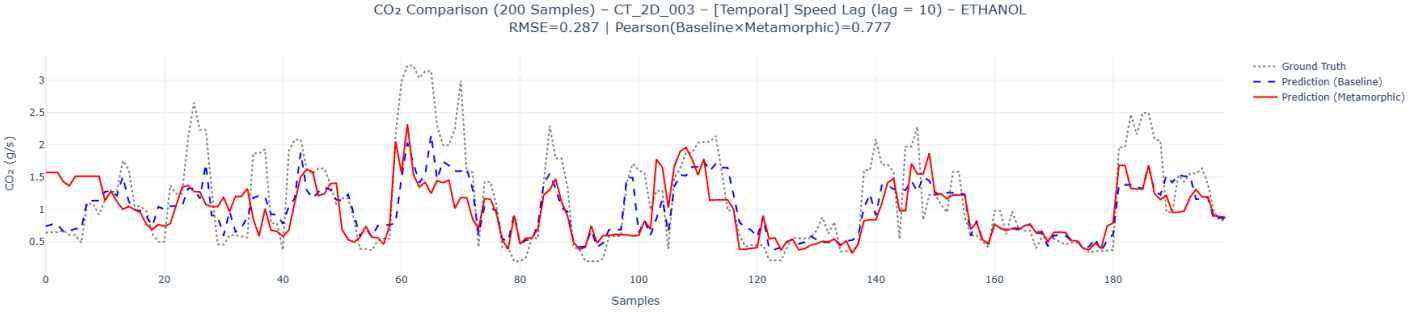
CT_2D_002 — Permutative Relation (Speed Lag = 5) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 0.3173
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.911
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.735



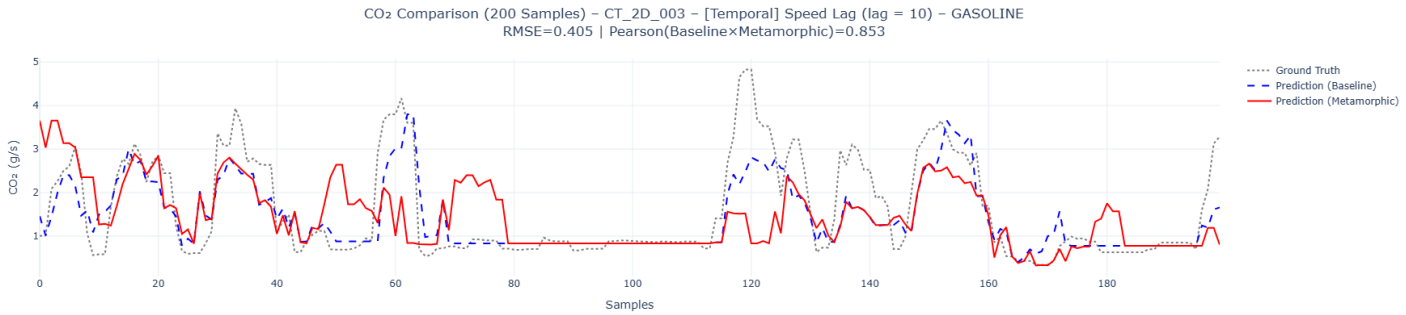
CT_2D_003 — Permutative Relation (Speed Lag = 10) — Ethanol

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



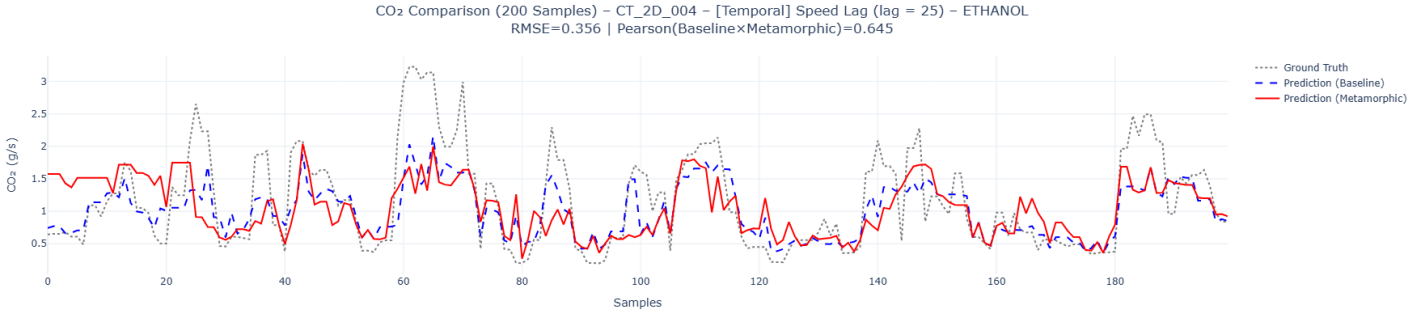
CT_2D_003 — Permutative Relation (Speed Lag = 10) — Gasoline

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



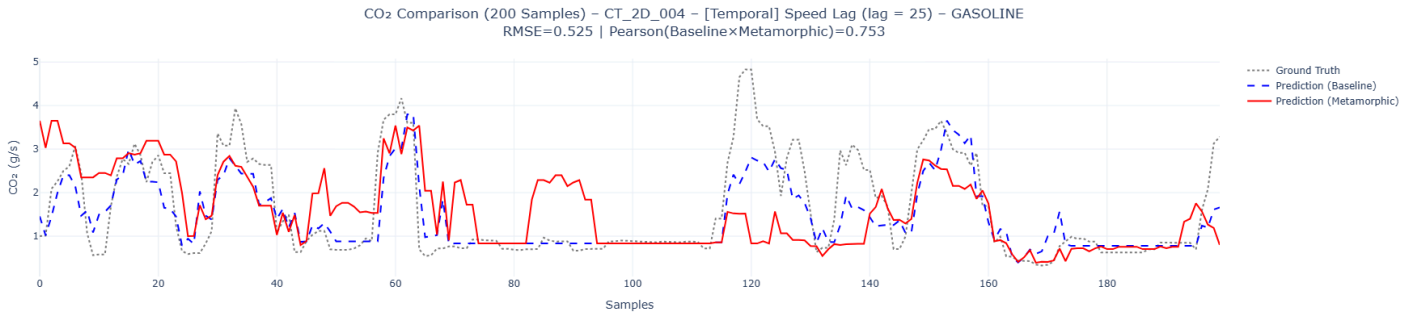
CT_2D_004 — Permutative Relation (Speed Lag = 25) — Ethanol

- **RMSE (Baseline × Metamorphic Prediction):** 0.3559
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.645
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.502



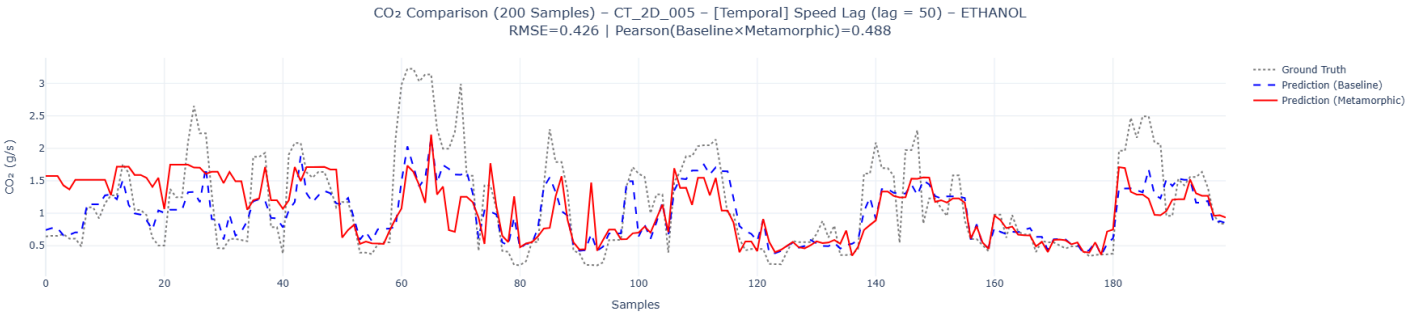
CT_2D_004 — Permutative Relation (Speed Lag = 25) — Gasoline

- **RMSE (Baseline × Metamorphic Prediction):** 0.5248
- **Pearson Correlation (Baseline × Metamorphic Prediction):** 0.753
- **Pearson Correlation (Ground Truth × Metamorphic Prediction):** 0.587



CT_2D_005 — Permutative Relation (Speed Lag = 50) — Ethanol

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



CT_2D_005 — Permutative Relation (Speed Lag = 50) — Gasoline

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