Towards an Integrated Surveillance for Lassa fever: Evidence from the Predictive Modeling of Lassa fever Incidence in Nigeria.

Rebekah Lamai Gambo, Isah Charles Saidu, Yaknan John Gambo, Christian Rummel, Dominik Bohler, Sabine Dittrich

June 19, 2025

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Outline

Dataset: Overview

Climate and Case Count Data

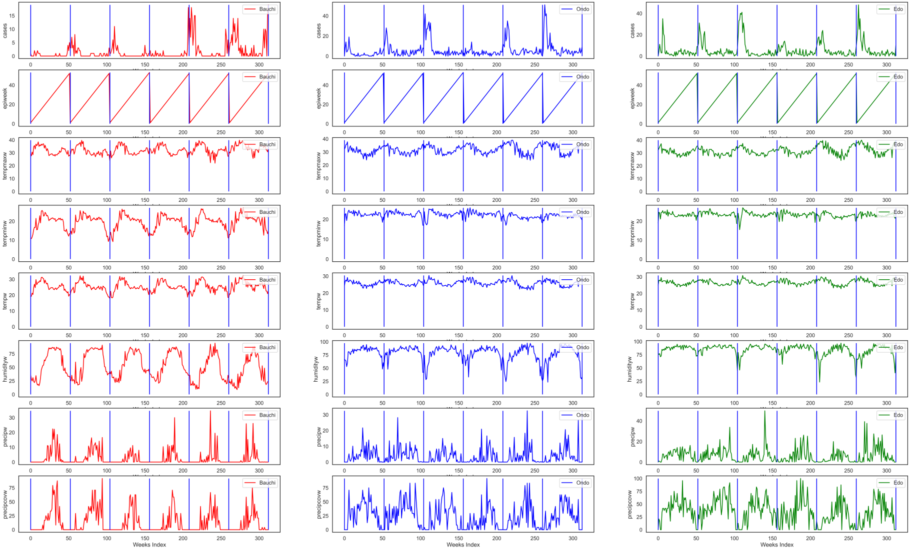
Data Overview:

- Weekly Lassa fever case counts for Bauchi, Edo, and Ondo states (Nigeria)
- Time period: January 2018 – December 2024
- Corresponding weekly climate data collected over the same period

Climate Variables (per week):

- Minimum Temperature
- Maximum Temperature
- Average Temperature
- Precipitation
- Precipitation Coverage
- Average Humidity

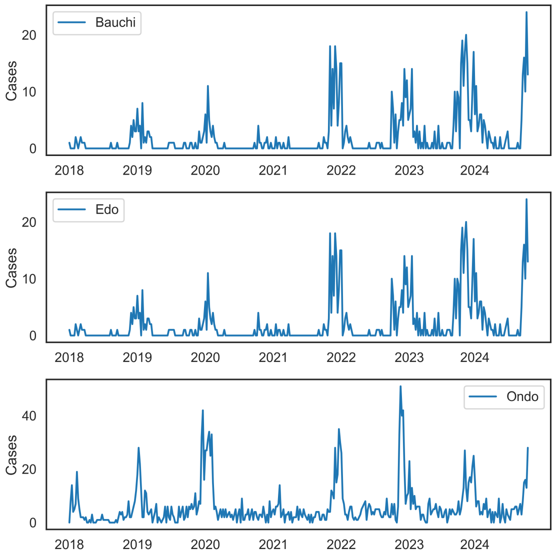
Dataset: Plots



Observations - The data appears to exhibit characteristics of a stationary stochastic process.

Dataset

Data - Per State



Data Split and Training Plan

Data Split:

- **Train:** 2018–2022 (per-state data)
- **Test:** 2023, 2024 (with prior context)

Modeling Strategies:

- LSTM
- MAR

Experiment Variants:

- **State-wise:** One model per state
  - 7D input $\rightarrow$ 7D output (climate + cases)
  - 7D input $\rightarrow$ 1D output ((climate , previous cases)$\rightarrow$ cases)
- **Unified:** One model across all states

Modeling Choices

Non-linear Model: Long Short-Term Memory (LSTM)

Prediction Variants:

Single-output (Lassa case count only):

$$y_t = f\left(\{\mathbf{y}_{t-i}\}_{i=1}^{4}; \mathbf{w}\right)$$

Multivariate output (case count + climate variables):

$$\mathbf{y}_t = f\left(\{\mathbf{y}_{t-i}\}_{i=1}^{4}; \mathbf{w}\right)$$

Where:

f	: LSTM prediction function
$y_t \in \mathbb{Z}^+$	: Predicted Lassa fever case count at time t
$\mathbf{x}_{t-i} \in \mathbb{R}^6$	: Climate variables at time $t - i$
$\mathbf{y}_t = (\mathbf{x}_t, y_t) \in \mathbb{R}^7$	: Full observation vector (climate + cases)
t	: Discrete time step (e.g., week)
$\mathbf{w}$	: Trainable parameters of the LSTM model

LSTM Model: Training Loss Function

Given: Training dataset (time index omitted for clarity)

$$\mathcal{D} = \{(\mathbf{x}_i, \mathbf{y}_i)\}_{i=1}^{n}, \quad \mathbf{x}_i \in \mathbb{R}^d, \quad \mathbf{y}_i \in \mathbb{R}^m$$

Loss Function:

$$\mathcal{L}(\mathbf{w}) = \frac{1}{n}\sum_{i=1}^{n} \underbrace{\left\| f_{\mathbf{x}_i} - f(\mathbf{x}_i; \mathbf{w}) \right\|^2}_{\text{MSE loss (climate features)}} + \underbrace{\sum_{i=1}^{n} [f_y - y_i \log f_y]}_{\text{Poisson loss (case count)}} + \lambda \underbrace{\sum_{i=1}^{n} (\Delta f_y)^2}_{\text{Smoothness penalty}}$$

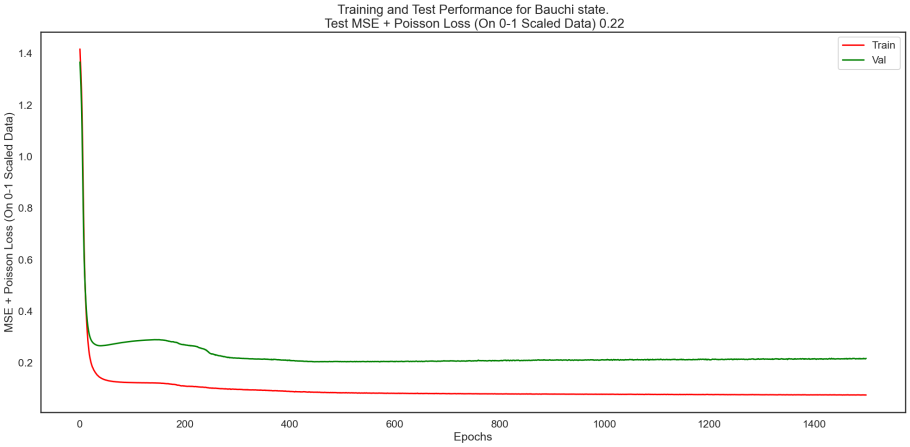
Where:

- $f(\mathbf{x}_i; \mathbf{w})$: LSTM output for all targets
- f_y: LSTM prediction of Lassa fever cases (scalar)
- $f_{\mathbf{x}_i}$: LSTM prediction of climate variables (multi-output case)
- $\Delta f_y = f_{y,t+1} - f_{y,t}$: First-order difference (temporal smoothness)
- $\mathbf{w}$: Trainable LSTM parameters
- λ: Smoothness regularization weight (e.g., 0.3)

LSTM (Per-State Model) — Bauchi: Training Loss

Variant: All Variables — One Model per State

Training Loss Curve



LSTM (Per-State Model) — Bauchi: Predictions

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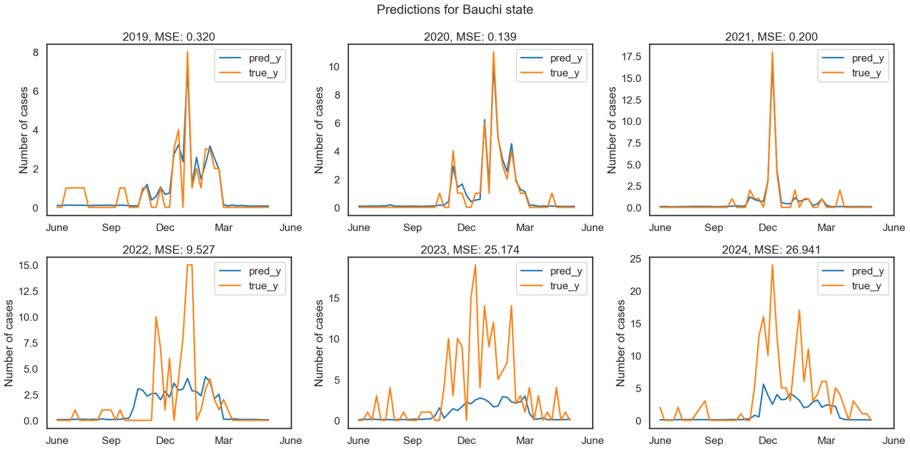
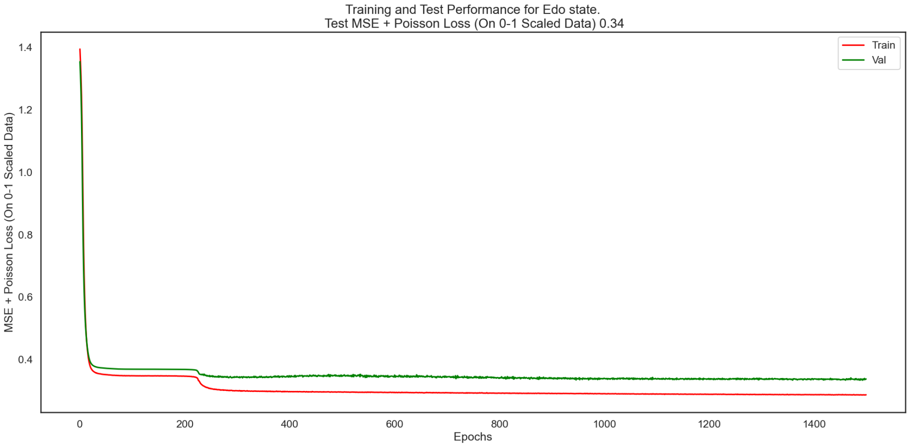
Training and Test Predictions



LSTM (Per-State Model) — Edo: Training Loss

Variant: All Variables — One Model per State

Training Loss Curve



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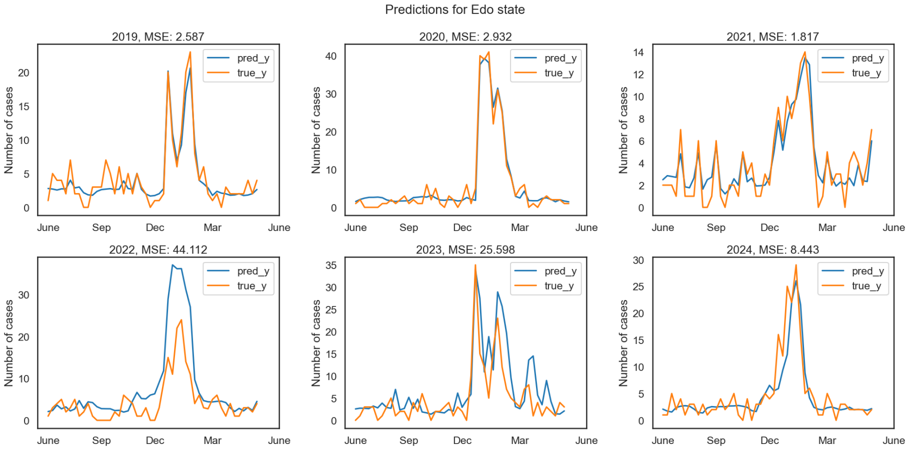

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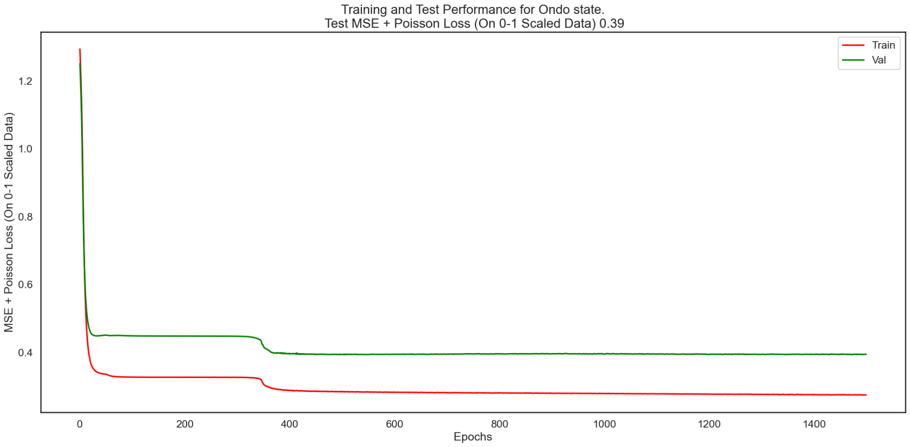

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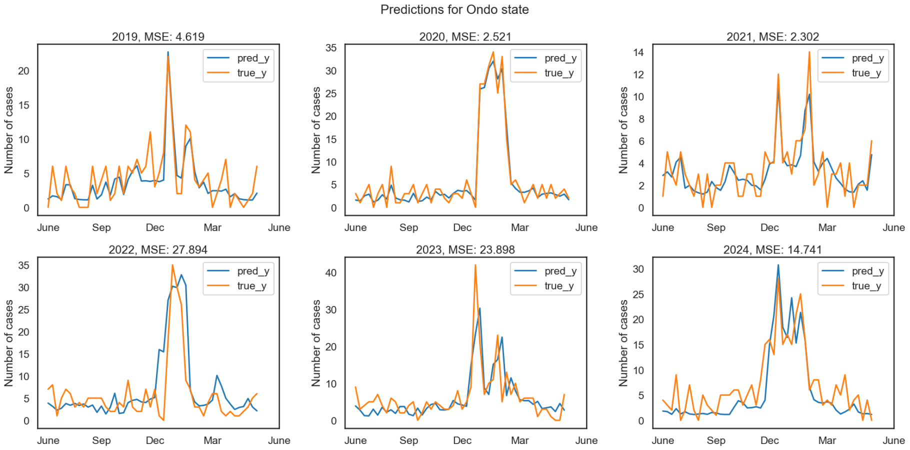

LSTM (Per-State, One-Output) — Bauchi: Training Loss

Variant: One Output — One Model per State

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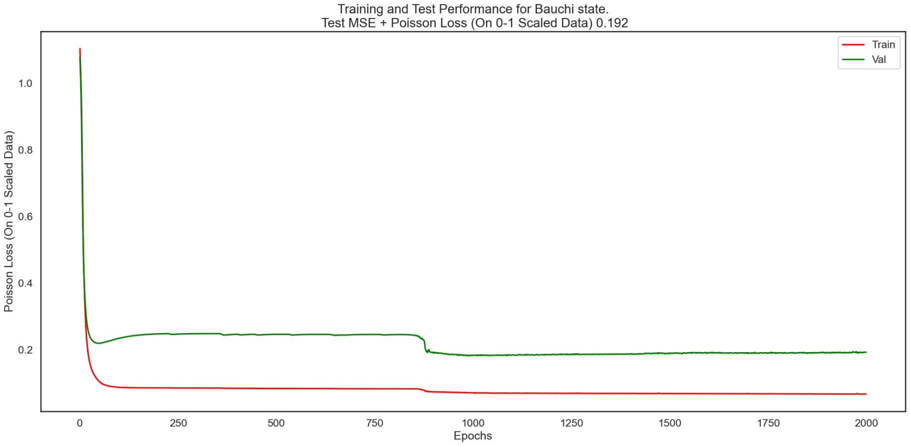

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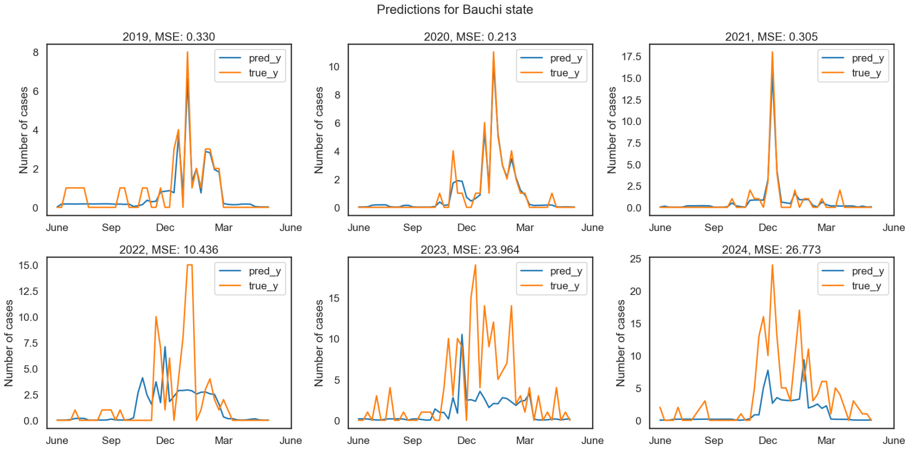

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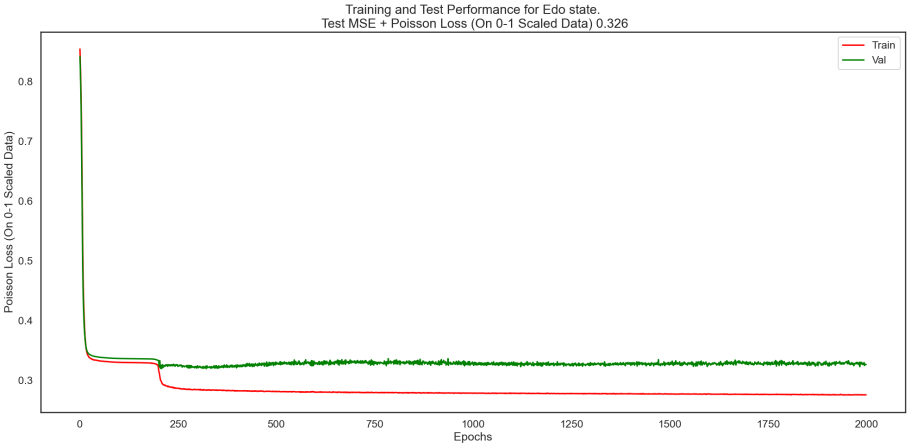

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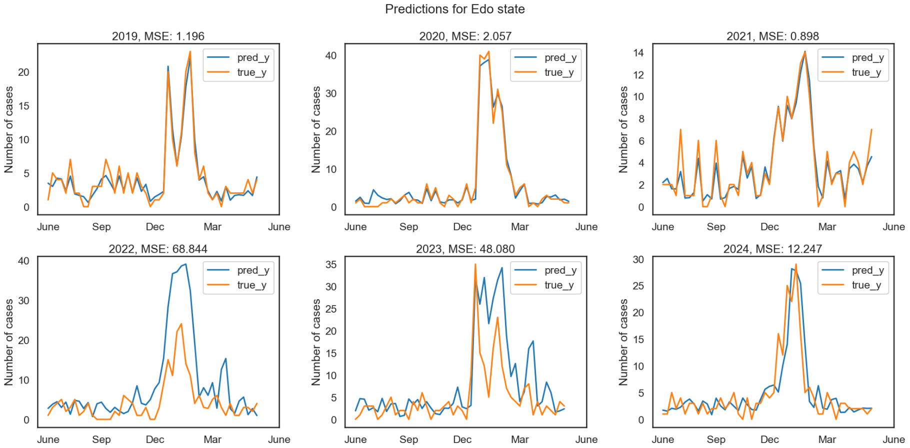

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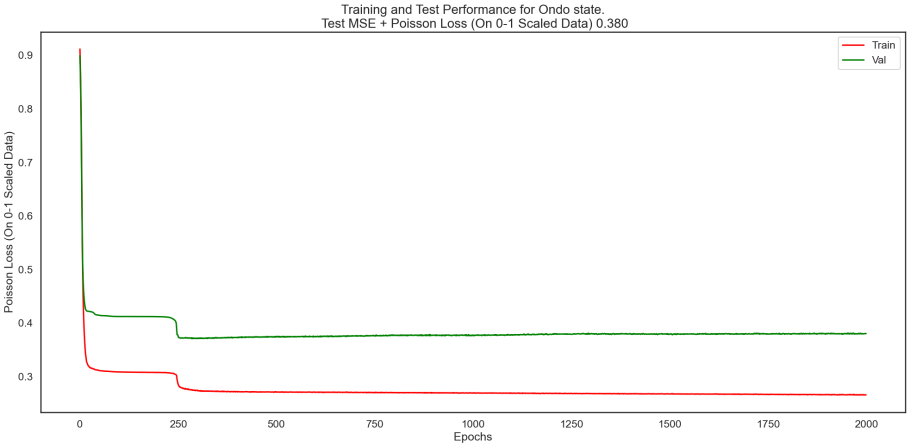

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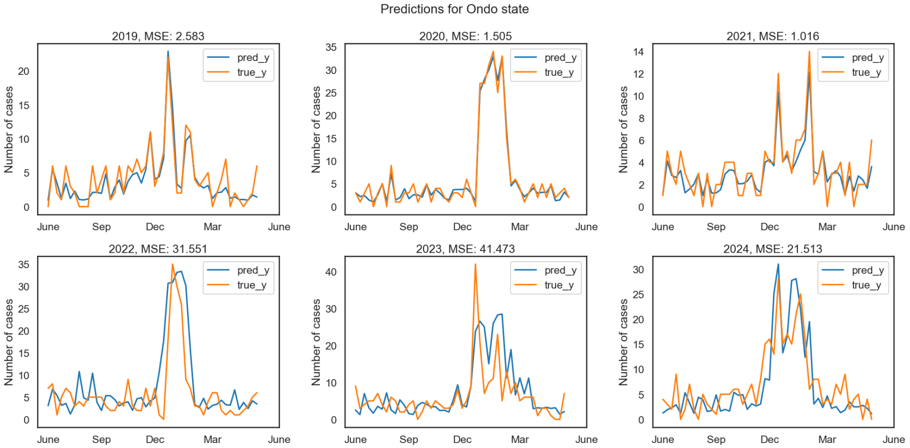
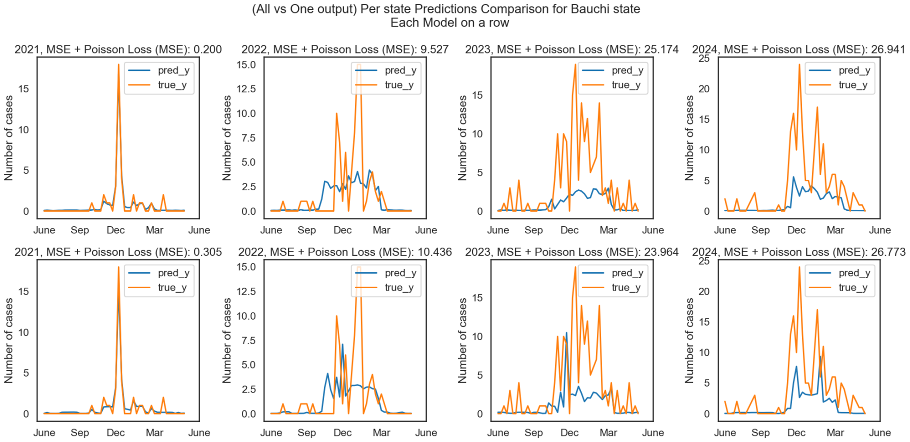


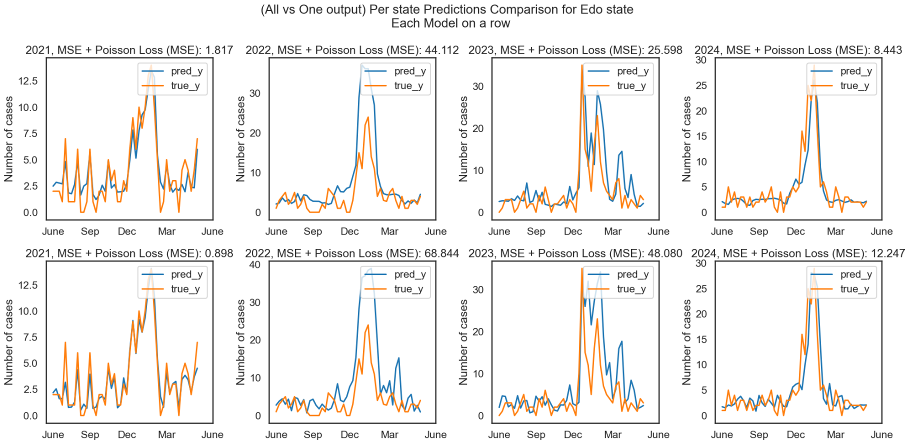
Per-State Model Comparison: All vs One – Bauchi Predictions

All vs One – Output: Bauchi Predictions



Per-State Model Comparison: All vs One – Edo Predictions

All vs One – Output: Edo Predictions



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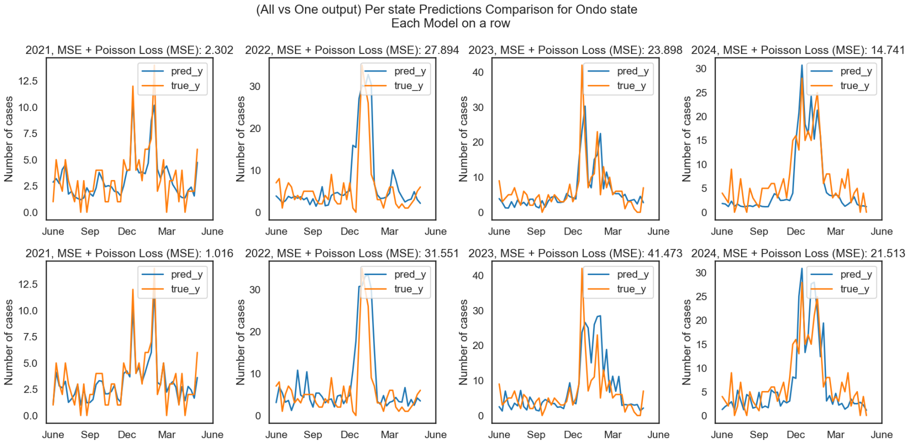
All vs One – Output: Ondo Predictions



MAR(4) Model for Climate and Lassa Fever Cases

Let $\mathbf{x}_t \in \mathbb{R}^7$ be the multivariate time series defined by:

$$\mathbf{x}_t = \begin{bmatrix} x_t^{(1)} \\ x_t^{(2)} \\ \vdots \\ x_t^{(6)} \\ x_t^{(7)} \end{bmatrix} = \begin{bmatrix} \text{climate}_t^{(1)} \\ \text{climate}_t^{(2)} \\ \vdots \\ \text{climate}_t^{(6)} \\ \text{lassa}_t \end{bmatrix}$$

The MAR(4) model is given by:

$$\boxed{\mathbf{x}_t := f(\mathbf{x}_{t-1}; \mathbf{A}) = \sum_{k=1}^{4} A_k \mathbf{x}_{t-k} + \boldsymbol{\epsilon}_t, \quad \boldsymbol{\epsilon}_t \sim \mathcal{N}(\mathbf{0}, \Sigma)}$$

Lassa fever dynamics (7th component):

$$x_t^{(7)} = \sum_{k=1}^{4} \sum_{j=1}^{7} A_k^{(7,j)} x_{t-k}^{(j)} + \epsilon_t^{(7)}$$

MAR(4) Model — One-Output Variant

In the one-output version of the MAR(4) model, only Lassa fever cases are predicted based on the past values of climate variables:

$$\boxed{y_t = \sum_{k=1}^{4} A_k \mathbf{x}_{t-k} + \epsilon_t, \quad \epsilon_t \sim \mathcal{N}(0, \sigma^2)}$$

Where:

- $\mathbf{x}_t \in \mathbb{R}^7$: vector of climate variables and the number of cases at time t
- $A_k \in \mathbb{R}^{1\times 7}$: autoregressive weight matrices
- y_t: predicted number of Lassa fever cases at time t

Training Objective

Let $\mathcal{D} = \{(\mathbf{x}_i, \mathbf{y}_i)\}_{i=1}^{n}$ be the dataset, and let $f(\mathbf{x}_i; \mathbf{A})$ denote the model's prediction. To reduce clutter, we omit the explicit time index t.

Training Loss Function:

$$\boxed{\mathcal{L}(\mathbf{A}) = \frac{1}{n} \sum_{i=1}^{n} \|\mathbf{x}_i - f(\mathbf{x}_i; \mathbf{A})\|^2 + \lambda \sum_{j=1}^{d} \max(0, -\mathbf{y}_j)}$$

Where:

- $\mathbf{A}$: model coefficient matrices (e.g., MAR parameters)
- $\max(0, -\mathbf{y}_j)$: regularization term penalizing negative outputs, enforcing $\mathbf{y}_j \geq 0$ for $j = 1, \ldots, d$
- $\lambda > 0$: regularization hyperparameter

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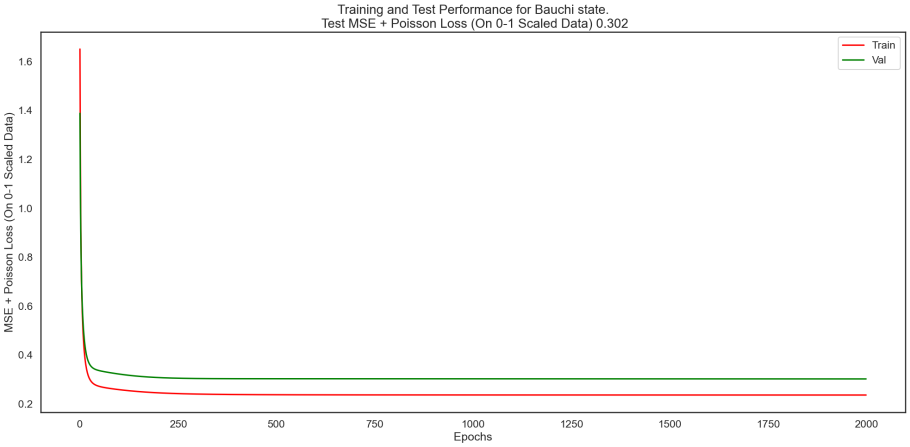
Variant: All Variables — One Mar Model per State

Training Loss Curve



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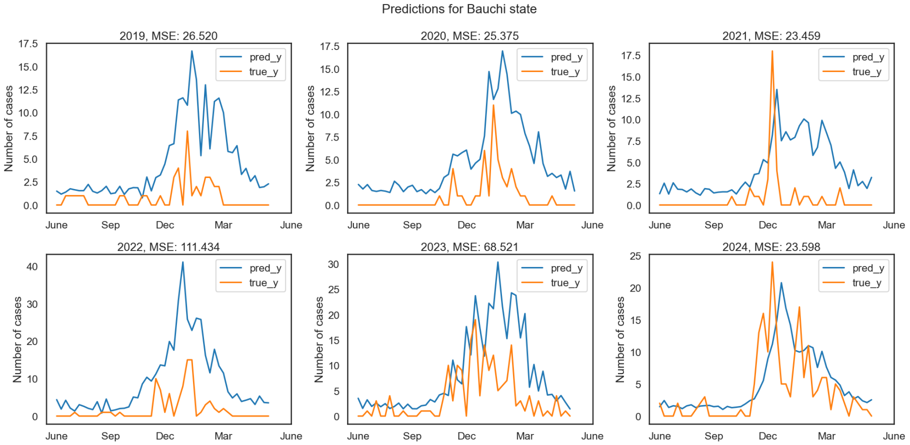
Training and Test Predictions



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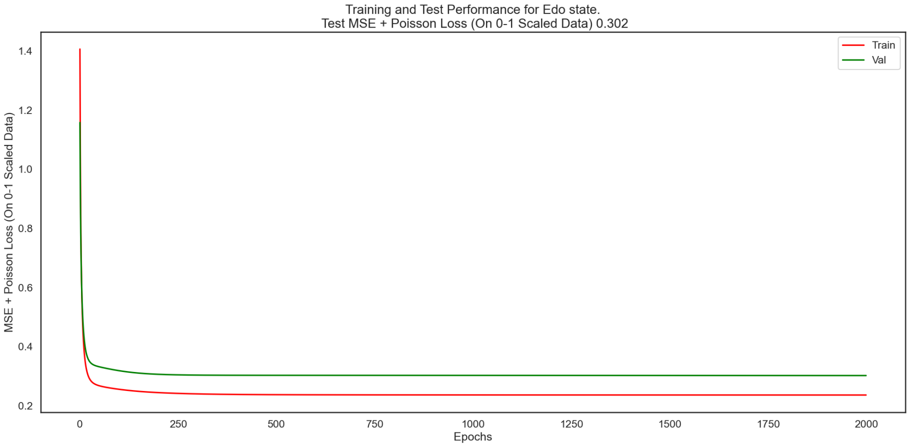

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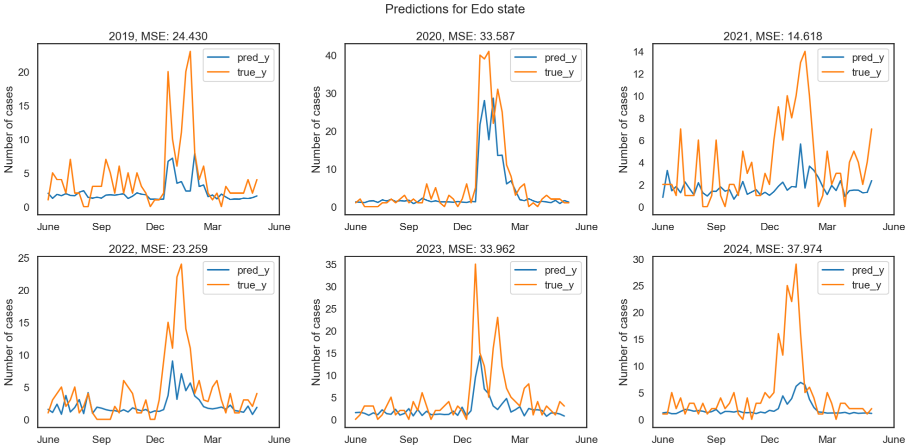

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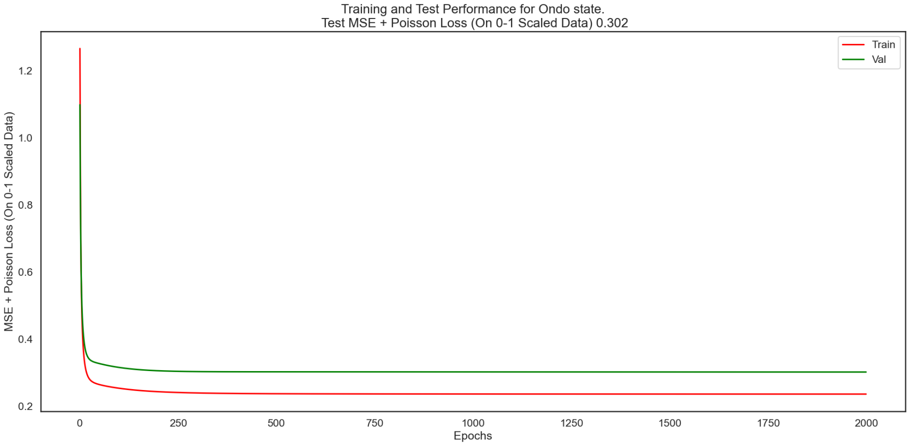

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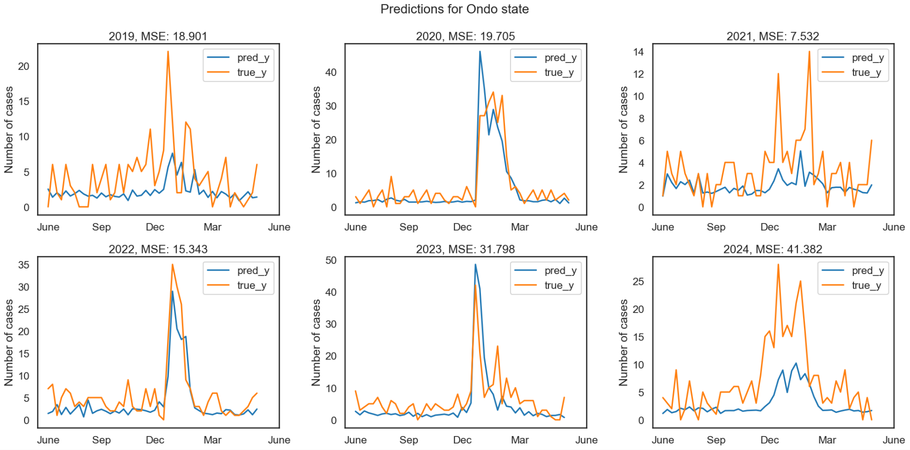

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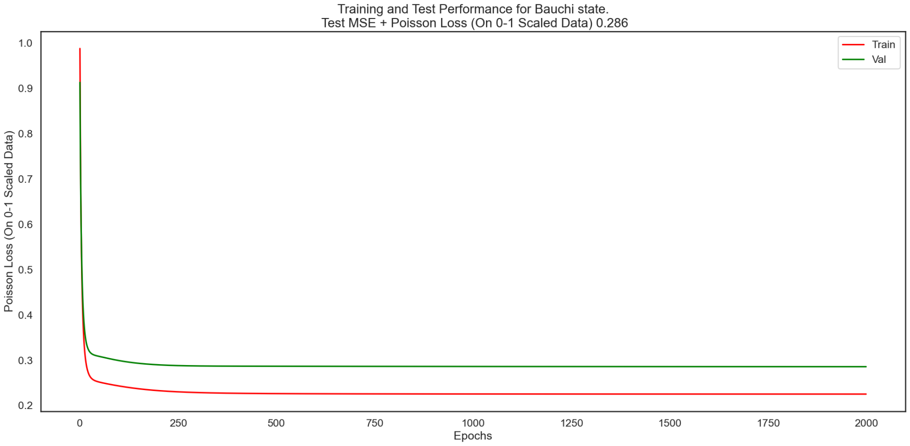

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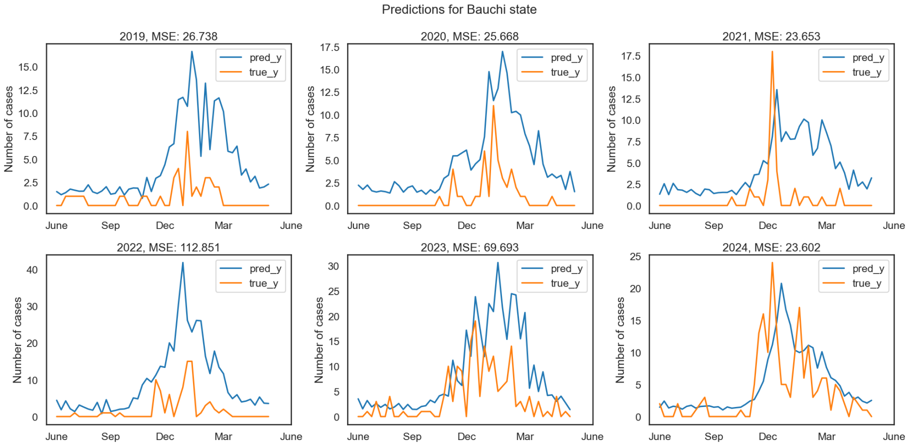

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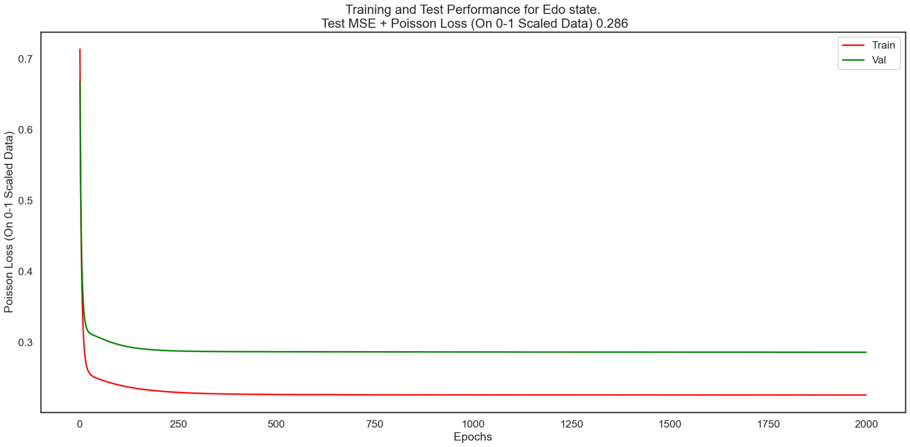

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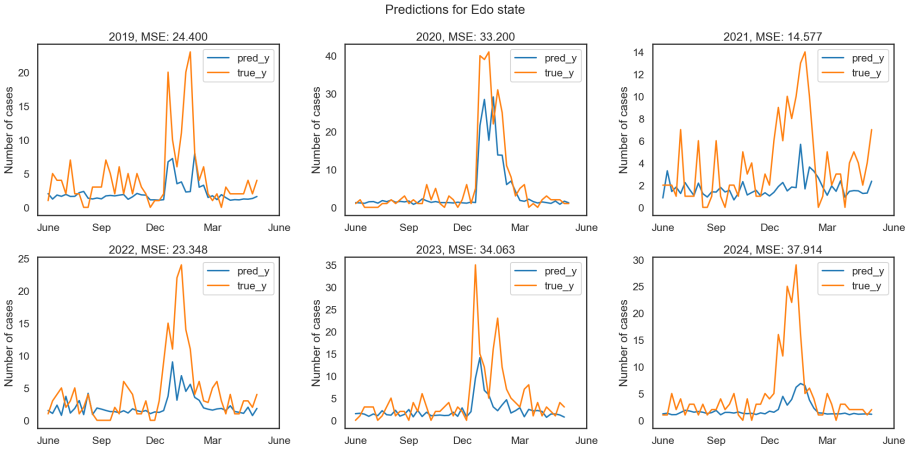

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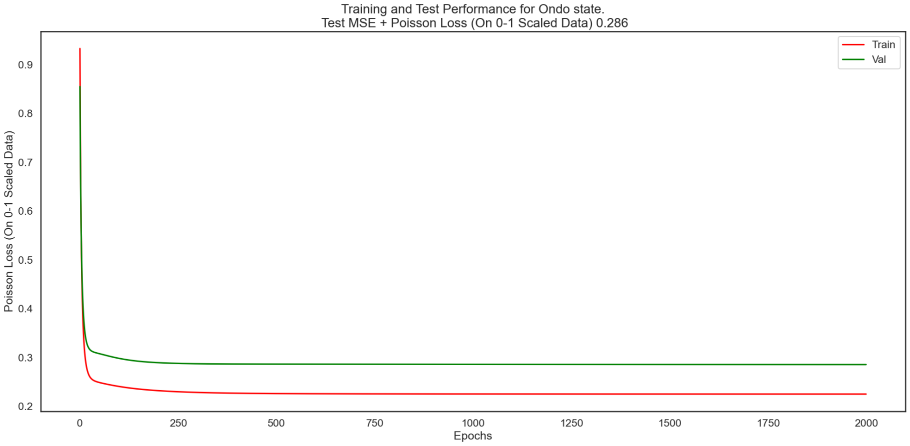

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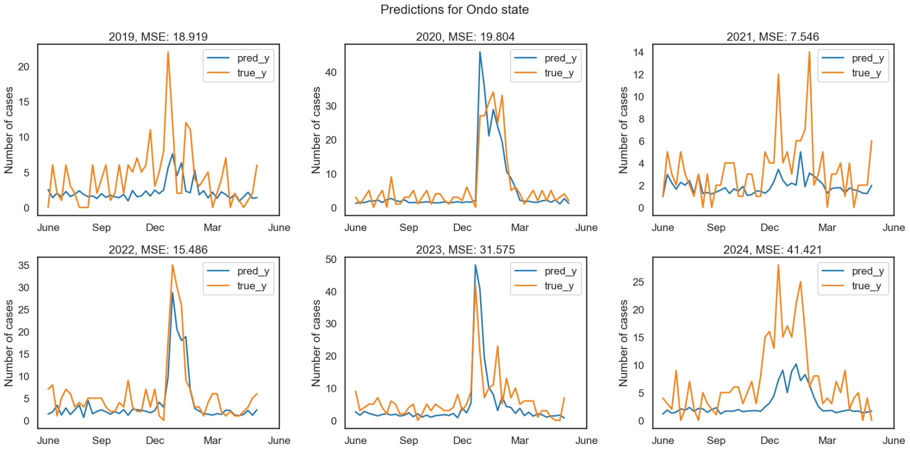

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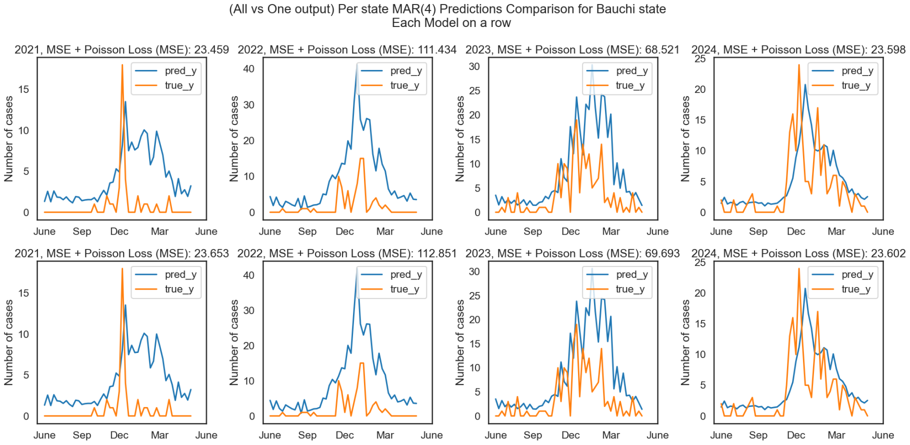
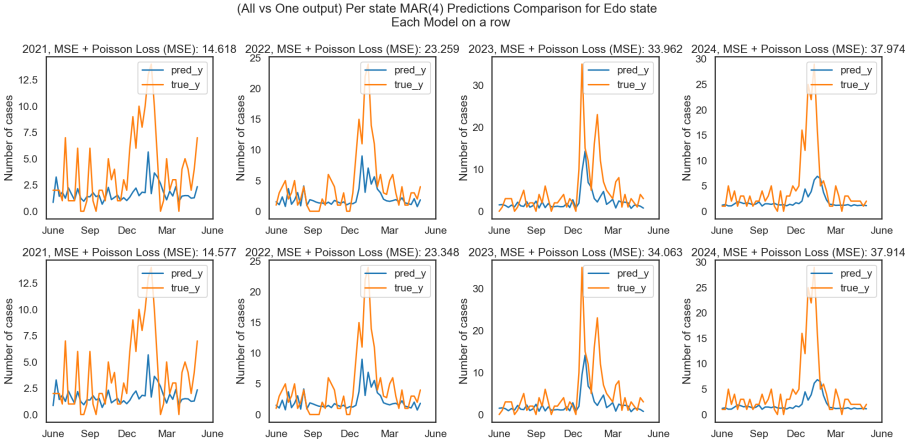


Per-State Model Comparison: All vs One – Edo Predictions

All vs One – Output: Edo Predictions



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