

# Hierarchical Time Series ARIMA Forecasting of Influenza-Derived SARS in Brazil

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# Why forecast influenza-derived SARS

## Hospital pressure

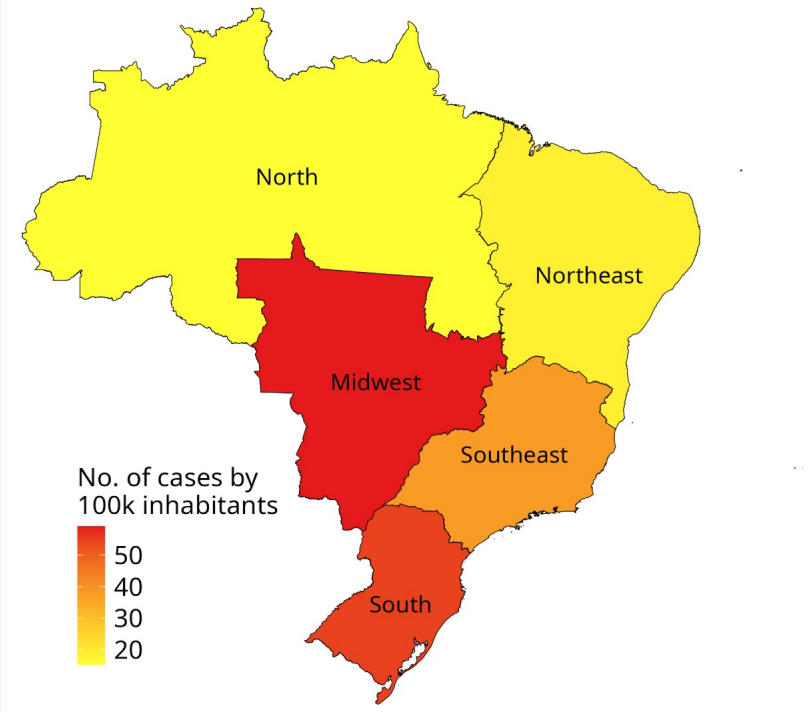
Influenza-associated SARS strains hospital capacity and drives mortality.

## Heterogeneous seasonality

Brazil's territorial extension produces distinct transmission dynamics across regions.

## SUS decisions

Forecasts guide vaccination planning and ICU bed allocation.




Influenza-derived SARS cases per 100 thousand inhabitants, by region



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THE PROBLEM

# Independent forecasts may not add up across levels

Goal: evaluate ARIMA in hierarchical time series (HTS) and measure the gain from reconciliation at the country, region and state levels.

# Data: influenza A and B SARS, 2019–2025

## 2019–2025

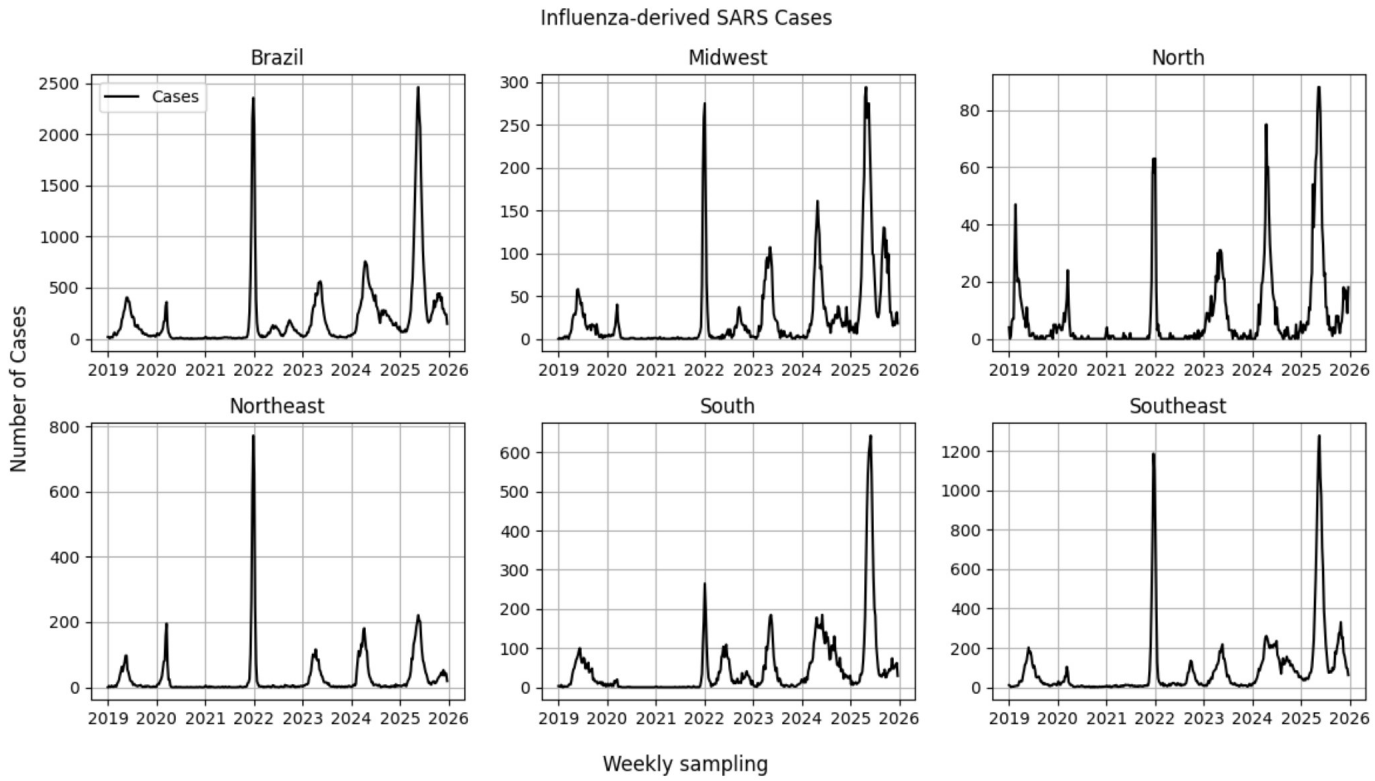
weekly case observations

## 33 series

1 country, 5 regions and 27 states

## DataSUS

Ministry of Health: influenza A and B SARS




Weekly influenza-derived SARS cases, Brazil and regions



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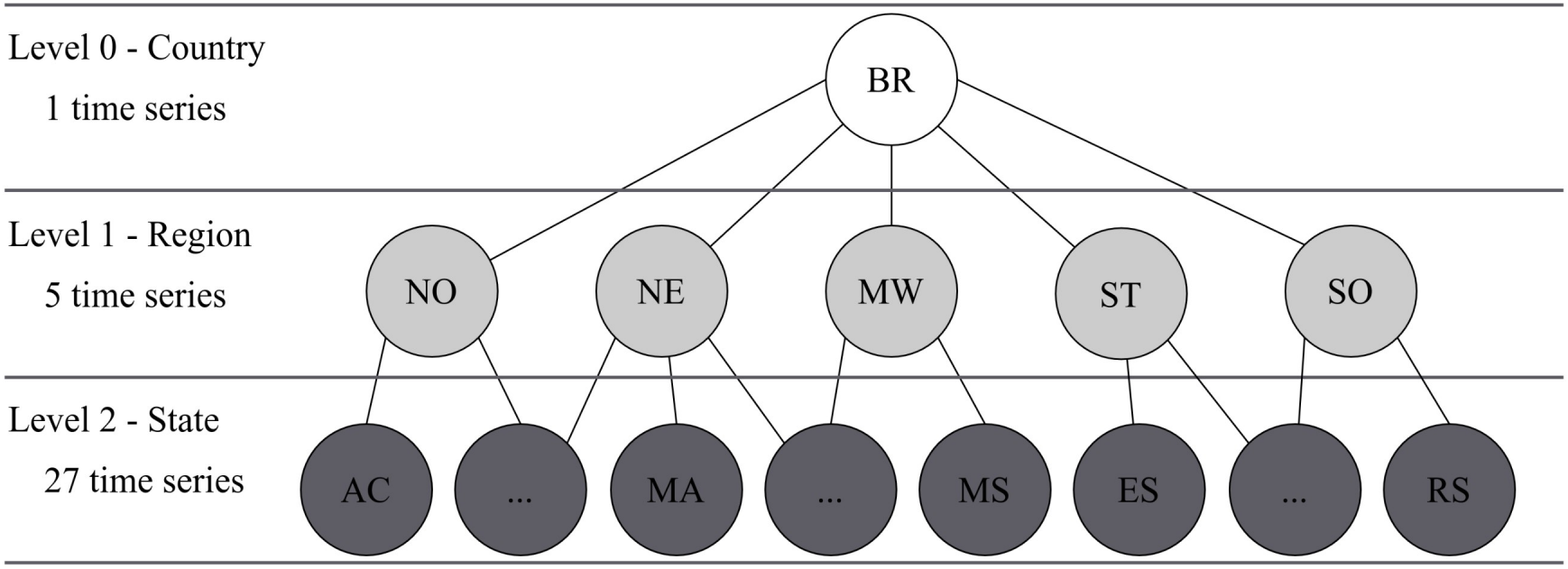
# Hierarchical structure: 33 series, 3 levels




**Coherence**

Country = sum of the 5 regions = sum of the 27 states

**Reconciliation**

Adjusts the base forecasts so that every level adds up

# Experimental workflow

| | | |
|---|---|---|
| 1 | **Data** | Weekly cumulative influenza-derived SARS cases, 2019–2025 |
| 2 | **Hierarchy** | Country → 5 regions → 27 states: 33 series in total |
| 3 | **Base model** | ARIMA(1,1,1) with seasonality 52, fitted to each series |
| 4 | **Validation** | Rolling window over 104 weeks; 1-, 2-, 4- and 8-week horizons |
| 5 | **Reconciliation** | BU, TDFP, OLS, WLS and MINTS on the base forecasts |
| 6 | **Evaluation** | RMSE, MAPE, improvement index (IP) and Diebold-Mariano test |



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# Five reconciliation approaches

| Method | How it reconciles |
|---|---|
| Bottom-Up (BU) | Sums the forecasts of the 27 states to obtain regions and country. |
| Top-Down (TDFP) | Splits the country forecast across regions and states using forecast proportions. |
| MinT-OLS (OLS) | Least squares: treats the errors of all series as equal and independent. |
| MinT-WLS (WLS) | Structural scaling: weights each series by the number of states it aggregates. |
| MinT-Shrink (MINTS) | Uses the estimated error covariance, with shrinkage, to minimize the variance of the reconciled errors. |

All start from the same ARIMA base forecasts. The reconciled models are named ARIMA_BU, ARIMA_TDFP, ARIMA_OLS, ARIMA_WLS and ARIMA_MINTS.



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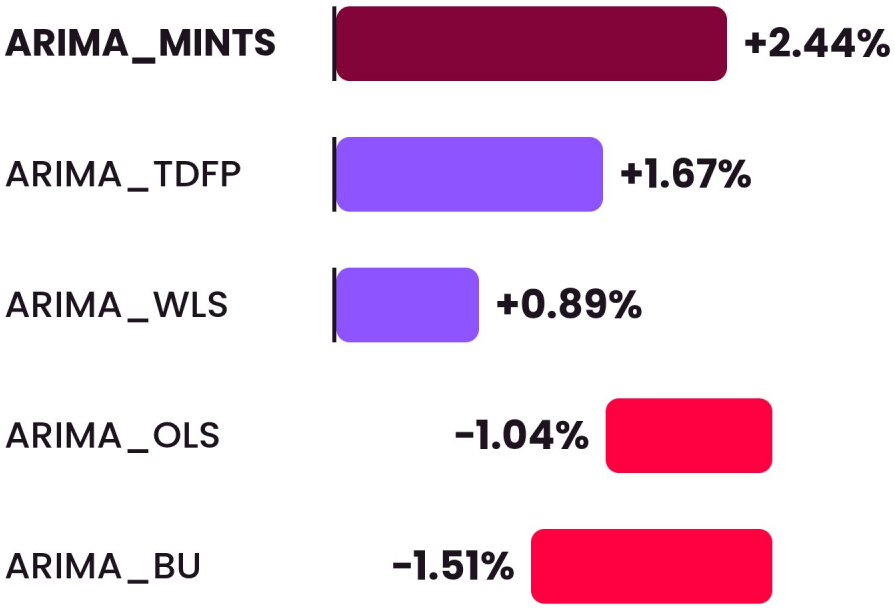
# MINTS leads the average gain over ARIMA

Average improvement index (IP, %) relative to the ARIMA baseline




BEST METHOD

**+2.44%**

average gain of ARIMA_MINTS over ARIMA, across all series, metrics and horizons

IP = (M_ARIMA - M_model) / M_ARIMA × 100



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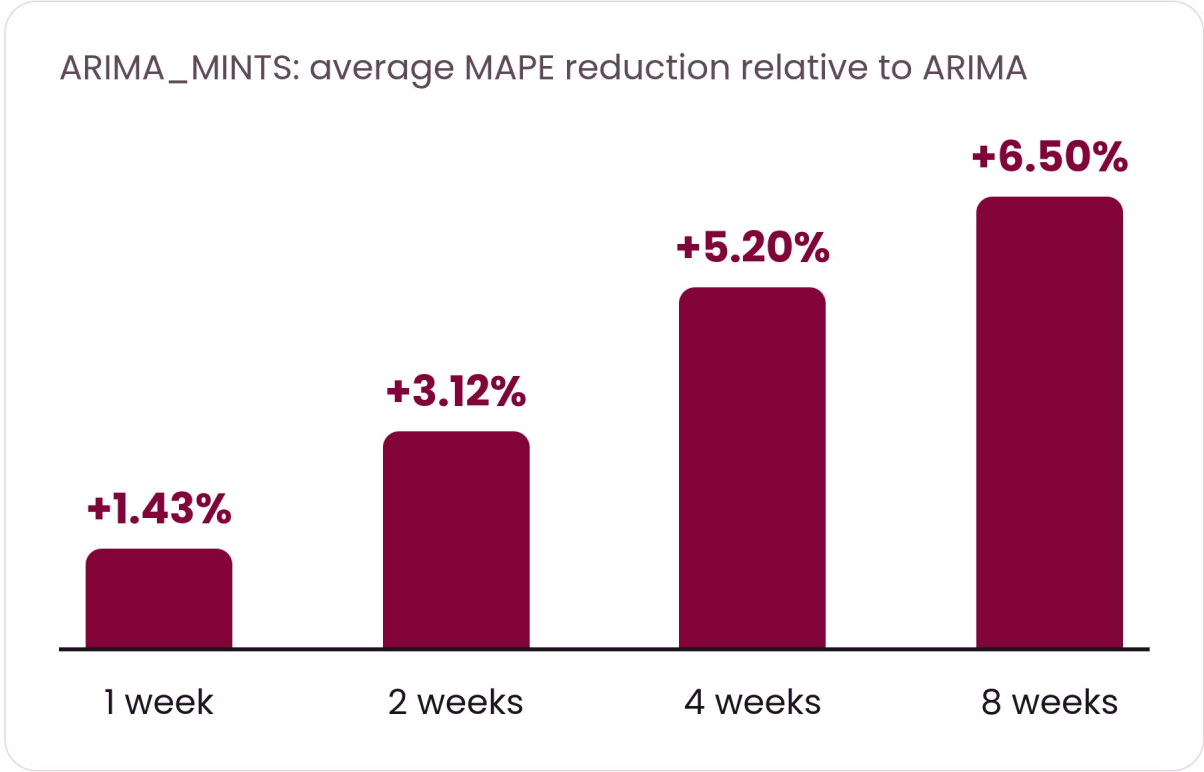
# Gains grow with the forecast horizon




### TDFP on RMSE

Gains of 3.34% at 2 weeks and 2.52% at 4 weeks.

### OLS is unstable

Alternates between gains and losses depending on the metric and horizon.

### At 8 weeks

BU has the lowest average RMSE (141.41); MINTS has the lowest MAPE (1.85%).

# More disaggregated, larger gain

COUNTRY

**−1.63%**

ARIMA already captures the aggregate series well; reconciling adds noise.

REGIONS

**+2.63%**

MINTS has the best average performance among the methods.

STATES

**+3.15%**

Largest average gain; TDFP (+1.76%) and WLS (+1.35%) follow.

Average IP of ARIMA_MINTS by level, relative to the ARIMA baseline (RMSE and MAPE, 1 to 8 weeks)

**The more disaggregated the level, the larger the gain from reconciliation.**



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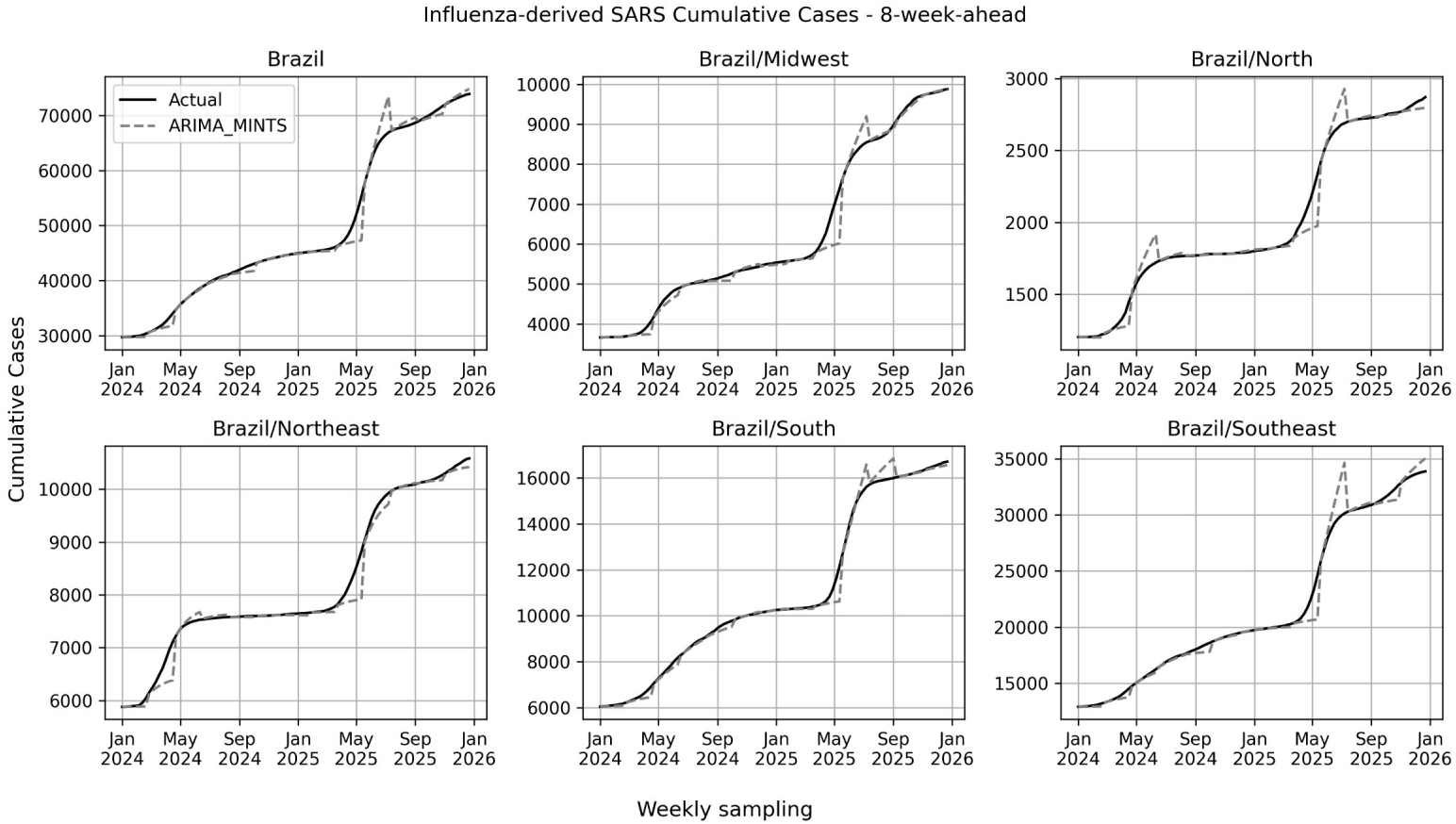
# ARIMA_MINTS tracks the series at 8 weeks



# Significance: gains at 1-week forecasts

1-week horizon: best model versus the alternatives (DM statistic in parentheses; p < 5%)

| Level | Best model | Significantly outperformed |
|---|---|---|
| Country | ARIMA / TDFP | None |
| Regions | ARIMA_MINTS | BU (-2.79) and WLS (-2.68) |
| States | ARIMA_MINTS | ARIMA (-2.94), BU (-2.94), OLS (-3.24) and WLS (-2.61) |

**At 2, 4 and 8 weeks, no difference is significant at 5%, at any level.**



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# Conclusions and future work

### MINTS is the most consistent

Average IP of 2.44%, with gains of up to 6.50% in MAPE at 8 weeks.

### Disaggregation pays off

Gain of 3.15% at the state level; at the country level, ARIMA is already enough.

### Sophistication matters

BU and OLS do not always beat ARIMA; the error covariance makes the difference.

### Future work

- ML and deep learning within the HTS
- Exogenous variables: climate, demographics and mobility
- Alternative reconciliations and hybrid methods
- Other countries and other diseases



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# Thank you!

Questions and comments

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