Analysis of Spatiotemporal Dynamics of Respiratory Syncytial Virus in Japan

Jingyi Liang, Harish Nair, Saturnino Luz, You Li

Usher Institute, The University of Edinburgh

THE UNIVERSITY of EDINBURGH | usher institute

BACKGROUND

Respiratory syncytial virus (RSV) is the most common pathogen identified in lower respiratory tract infection in infants [1]. It poses a substantial burden of disease globally among children under five and elders. The traits of RSV activity are highly correlated with geographical location, with seasonal patterns varying significantly in different regions worldwide. The peak season of RSV occurs during autumn and winter in temperate regions and during rainy seasons in tropical regions. In Japan, RSV infection generally occurs during the autumn and winter.

The research intends to investigate the spatiotemporal patterns of RSV epidemics and identify climate drivers influencing RSV epidemics in Japan.

OBJECTIVES

- I. Investigate spatiotemporal patterns of RSV epidemics in Japan
- II. Identify the climate drivers that influence RSV epidemics in Japan
- III. Assess the geographic distribution of such climate influences in Japan
- IV. Forecast the RSV epidemics in Tokyo, Japan

METHODS

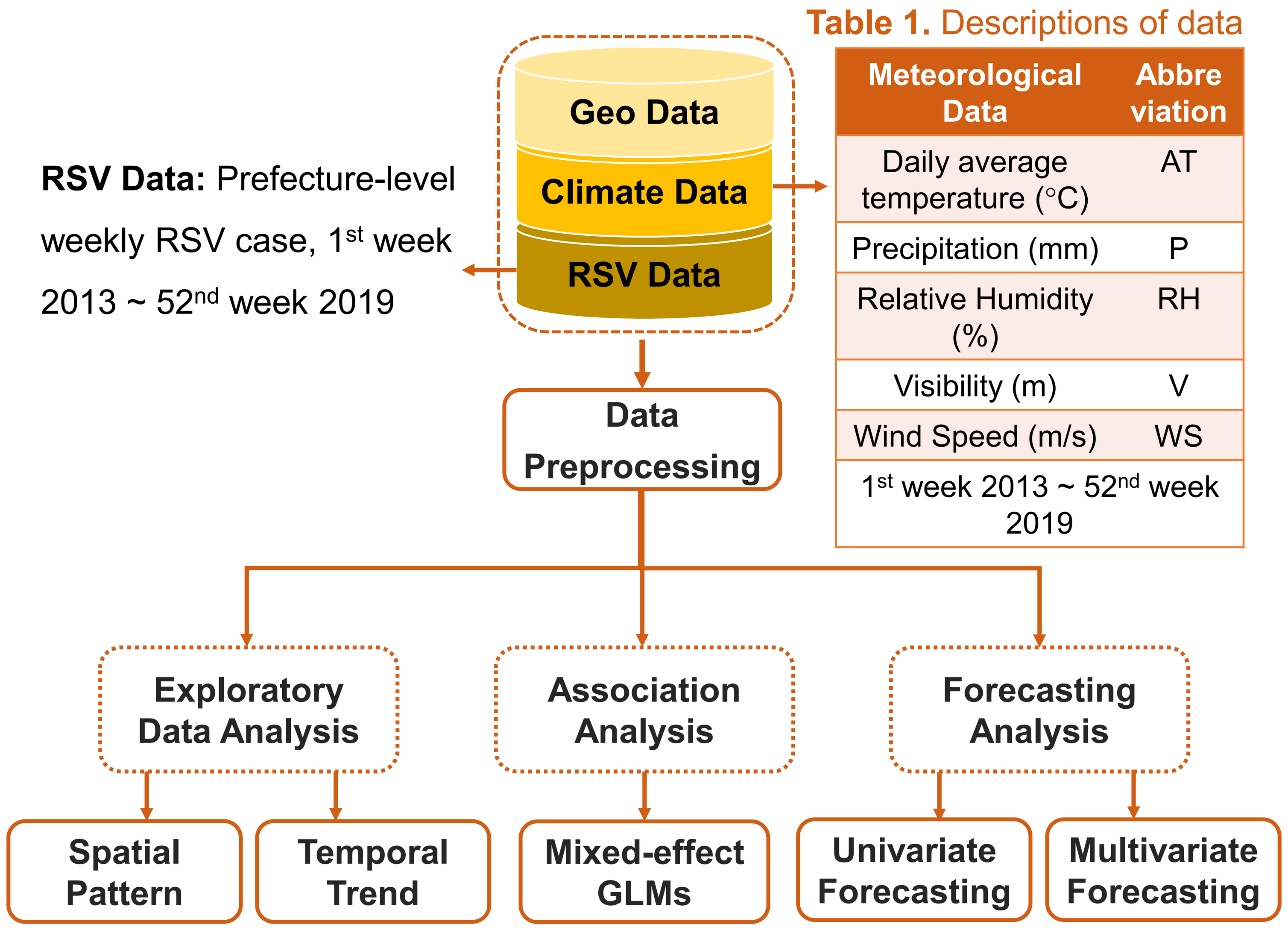

Table 1. Descriptions of data

Meteorological Data	Abbreviation
Daily average temperature (°C)	AT
Precipitation (mm)	P
Relative Humidity (%)	RH
Visibility (m)	V
Wind Speed (m/s)	WS
1st week 2013 ~ 52nd week 2019	

Figure 1. Flowchart of the methodology

Mixed-effect Generalized Linear Model

$$ln\left(E(Y_{ijt})\right) = \alpha_i + b_{ij} + c_{ij(t)} + \beta_{RH}X_{RH(ijt)} + \beta_{AT}X_{AT(ijt)} + \beta_V X_{V(ijt)} + \beta_P X_{P(ijt)} + \beta_{WS}X_{WS(ijt)} + \varepsilon_{ijt}, \varepsilon_{ijt} \sim AR_1(\rho)$$

Where $Y_{ijt} \sim Negative\ Binomial\ Distribution$, is the number of RSV-confirmed cases in prefecture i, year j and week t,

α_i is the overall mean of prefecture i,

$b_{ij} \sim N(0, \delta_b^2)$ is the random main effect of year j of prefecture i,

$c_{ij(t)} \sim N(0, \delta_c^2)$ is the random main effect of week t at year j of prefecture i,

β_k is the fixed main effect of the meteorological factor k,

$\varepsilon_{ijt} \sim N(0, \delta_e^2)$ is the error term, follows the stationary auto regressive $AR(1) \sim cov(\varepsilon_{ijt}, \varepsilon_{ijt*})$.

RESULTS

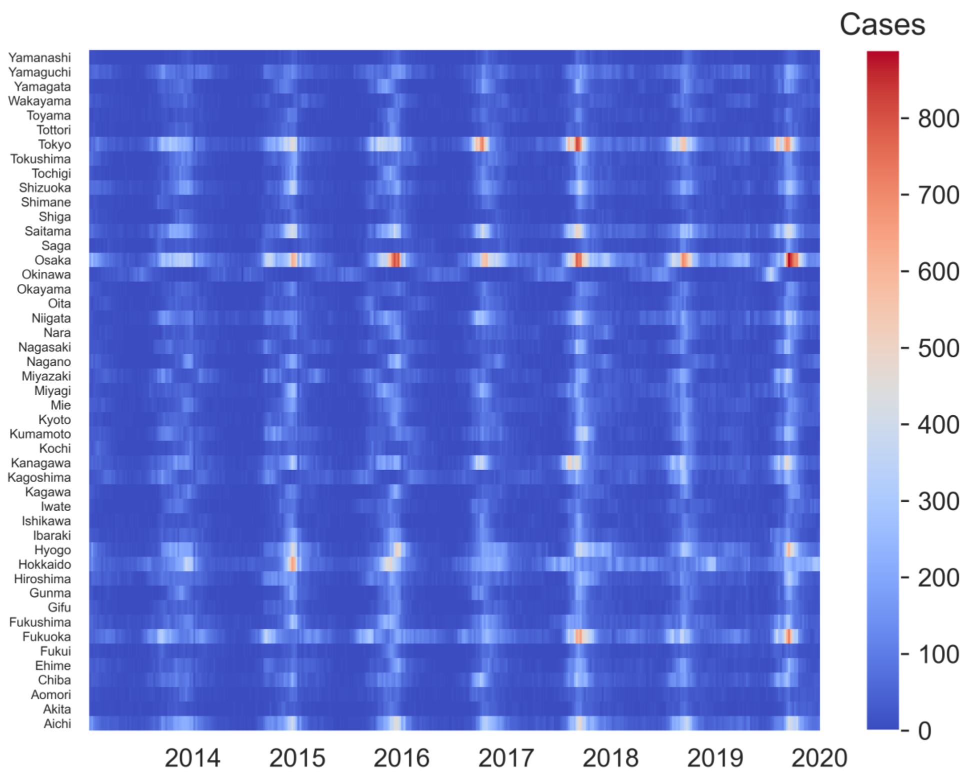

Figure 2. Time-series pattern of RSV cases in Japan during 2013-2019

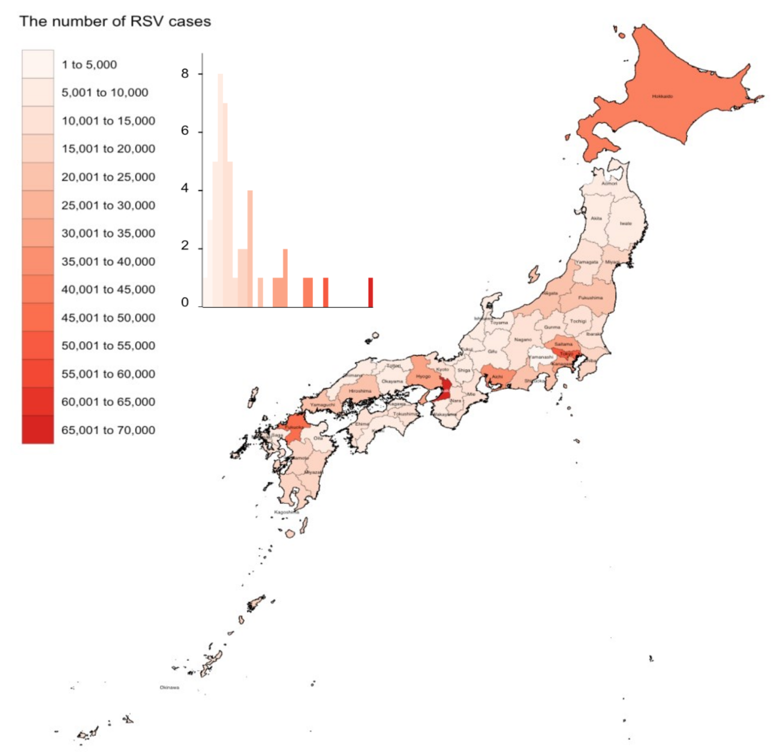

Figure 3. Spatial distribution of RSV cases in Japan during 2013-2019

Table 2. Pooled results of multivariate models for 47 prefectures in Japan

Meteorological Factor	Estimated Coefficients	95% CI	p-value	Heterogeneity (p-value)
Visibility	**0.0546**	**[0.0396; 0.0697]**	**< 0.0001**	**< 0.0001**
Relative Humidity	**0.0181**	**[0.0134; 0.0228]**	**< 0.0001**	**< 0.0001**
Average Temperature	**-0.0238**	**[-0.0326; -0.0149]**	**< 0.0001**	**< 0.0001**
Precipitation	-0.0241	[-0.0435; -0.0047]	0.0161	0.2067
Wind Speed	-0.0022	[-0.0164; 0.0120]	0.7562	< 0.0001

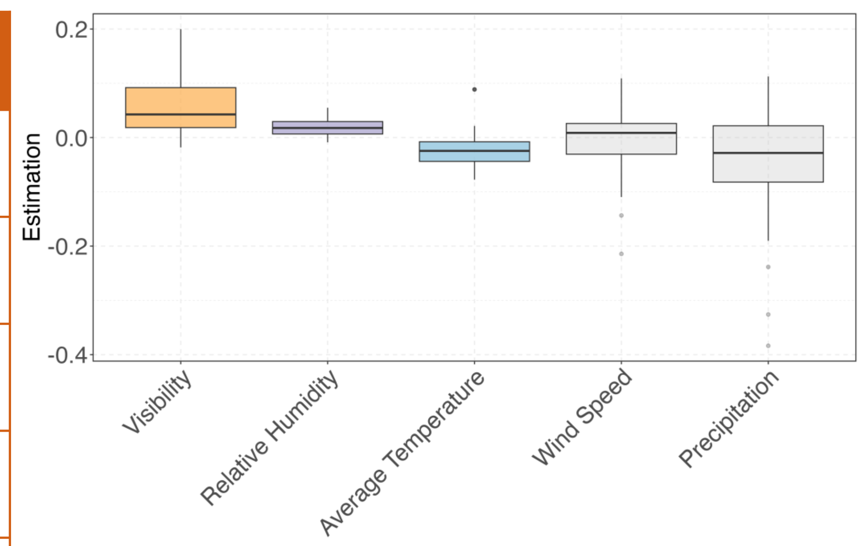

Figure 4. Distribution of associations among prefecture-level models in Japan

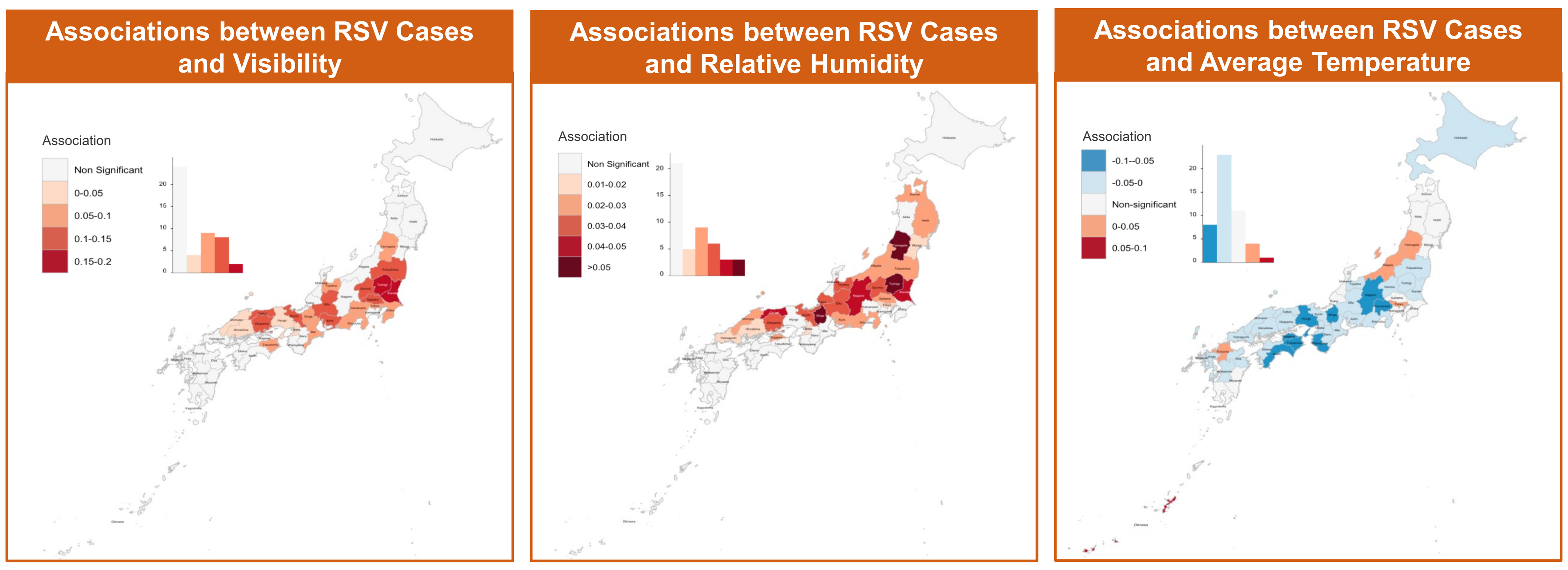

Figure 5. Maps of relationships between meteorological factors and RSV cases in Japan during 2013-2019

Table 3. Forecasting performance

Machine Learning Models	RMSE
Autoregressive Integrated Moving Average (ARIMA(1,1,0)(0,1,1)[52])	77.56
1D-Convolution and Long-Short Term Memory Network (Conv1D-LSTM)	72.18
Bi-directional Recurrent Neural Network (BRNN)	**59.87**

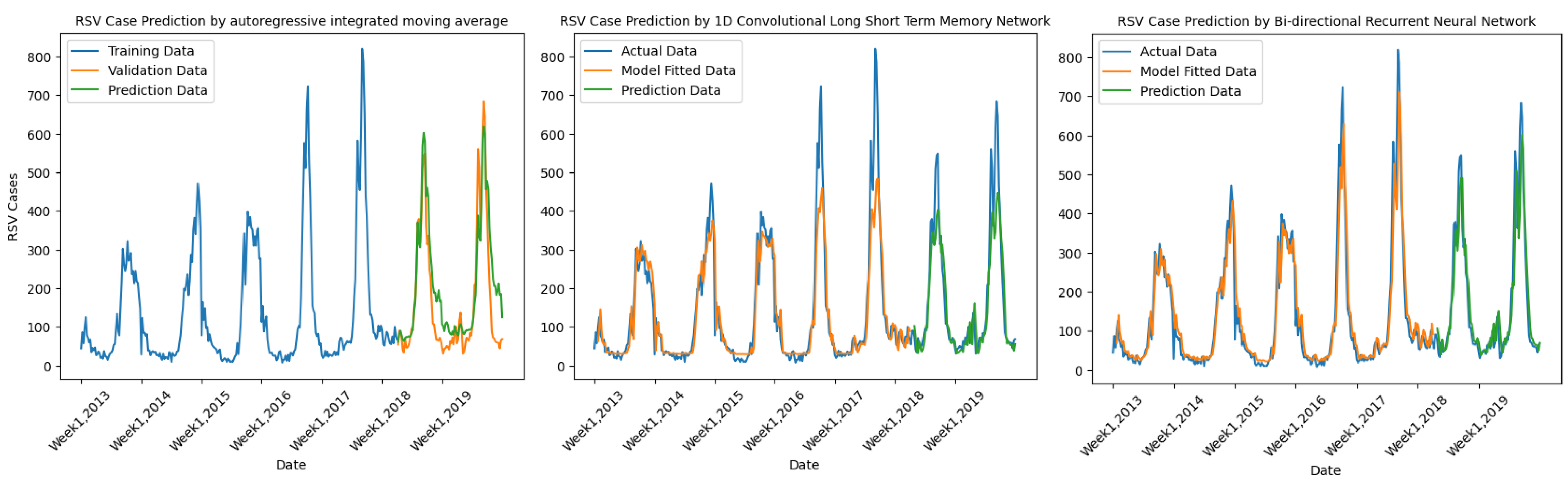

Figure 6. Forecasting plots of machine learning models of RSV cases in Tokyo, Japan

CONCLUSION

Our research indicates no apparent spatial pattern in RSV cases in Japan from 2013 to 2019. Meteorological factors exhibited heterogeneous impacts on RSV transmission across different prefectures, resulting in evident spatial clustering effects in specific associations. Our forecasting analysis demonstrated that BRNNs surpassed both ARIMA and LSTM models in predictive accuracy. This highlights the substantial promise of BRNNs for anticipatory modelling of future RSV epidemics.

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[1] Nair, Harish et al. "Global Burden Of Acute Lower Respiratory Infections Due To Respiratory Syncytial Virus In Young Children: A Systematic Review And Meta-Analysis". The Lancet, vol 375, no. 9725, 2010, pp. 1545-1555. Elsevier BV, doi:10.1016/s0140-6736(10)60206-1.

[2] Li, Y., Wang, X., Cong, B., Deng, S., Feikin, D. R., & Nair, H. (2022). Understanding the potential drivers for respiratory syncytial virus rebound during the coronavirus disease 2019 pandemic. *The Journal of Infectious Diseases*, *225*(6), 957–964. https://doi.org/10.1093/infdis/jiab606