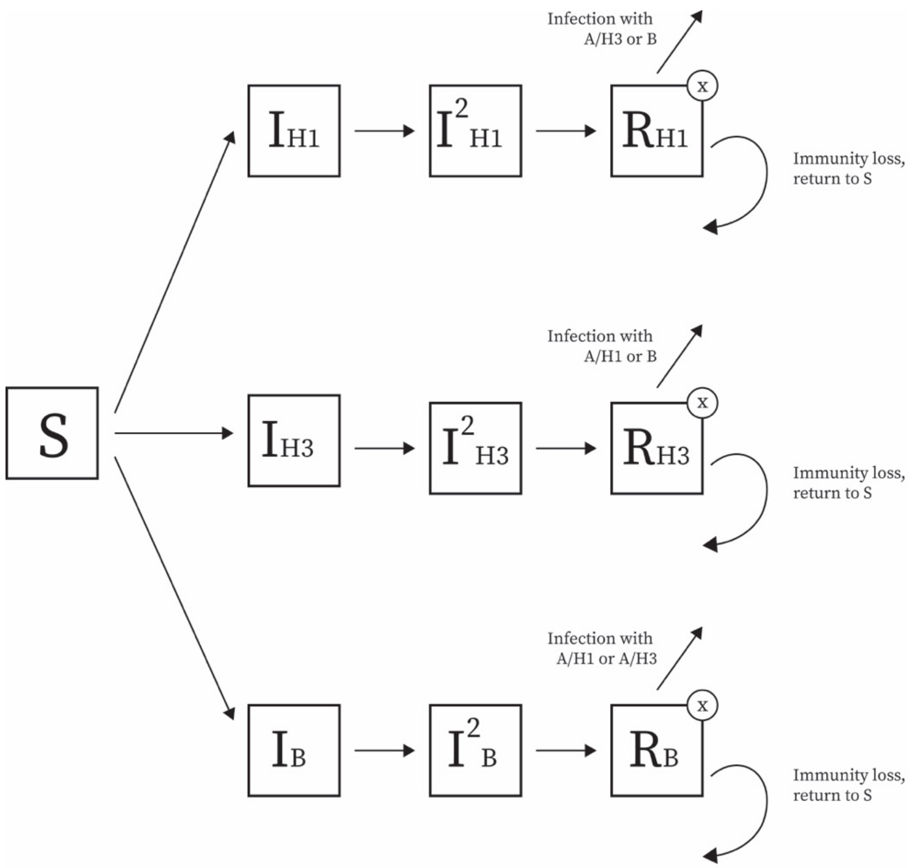
We adapted a previous model that incorporates three co-circulating (sub)types of influenza (A/H1N1, A/H3N2, B) to produce epidemics that do not follow consistent, cyclic patterns (Servadio et al., 2024). Each (sub)type follows SIRS dynamics, including a two-stage infected class and a multi-stage recovered class (Lloyd, 2001). Infection with one (sub)type confers full immunity during the recovery stages as well as partial immunity to the other two. Immunity wanes over time, and recovered individuals become susceptible again. Natural birth and death rates from Vietnam are incorporated in the model based on reported birth and death rates from the World Bank and World Health Organization, respectively (World Bank, n.d.; World Health Organization, 2020). We ran the model for an initial ten-year burn-in period and then examined the output from a second ten-year period to avoid observing major fluctuations in incidence when evaluating the model.

Parameter values that we assumed include natural birth and death rates as well as duration of infection (five days). The remaining parameters were estimated through parameter-space search: transmission parameters for each (sub)type, mean duration of immunity, and relative cross immunity among each pair of (sub)types (assumed symmetric).

We incorporated three variations in the model to assess whether certain model structures have a greater or lesser ability to produce nonannual epidemics as seen in the tropics. In the first variation, we considered five different numbers of recovery stages to represent variance in the duration of immunity among recovered individuals (2, 4, 6, 16, 48). In the second variation, we considered multiple subpopulations to represent different locations or groups with reduced social mixing between groups. We considered a single population, two subpopulations of equal size, and two subpopulations of unequal size (80:20 ratio). For the two model structures with subpopulations, two social mixing parameters were estimated in the parameter search to allow asymmetric influence from one subpopulation to another. In the third variation, we considered periodic case importation to represent introduction of cases from outside the model system, which can occur from infected individuals traveling into or returning to the model system. The number of days between importations was estimated through the parameter-space search. These three variations, through their combinations, lead to a total of 30 model structures.



S
I H1
I2 H1
R H1
x
Infection with A/H3 or B
Immunity loss, return to S
I H3
I2 H3
R H3
x
Infection with A/H1 or B
Immunity loss, return to S
I B
I2 B
R B
x
Infection with A/H1 or A/H3
Immunity loss, return to S

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