

Predicting Flu (Influenza) Epidemics

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Influenza disease is an important cause of morbidity to society. Each year, about 20% of children and 5% of adults worldwide develop symptomatic influenza. The disease is characterized by being season-dependent (e.g. winter outbreaks in non-tropical regimes), and by the fact that an individual can be infected with flu virus every year, because there are several flu virus types and moreover, strains within each type can mutate. In this work we aim to predict whether a particular flu virus type will outbreak.

To gain insights into the nonlinear dynamics of recurrent flu epidemics, we study the SIRC (Susceptible (S), Infectious (I), Recovered (R), Cross-immune (C)) epidemic model [1]. We assume no immune interference between the different flu virus types so we need consider only one virus type. The model describes the process of disease spread from individuals infected with the virus to those that are susceptible to it. Infected individuals eventually recover from the disease with short-term full immunity against the virus. After a short period of time, as the virus is changed due to mutations, recovered individuals turn into cross-immune and subsequently may become susceptible again. Cross-immune individuals, as oppose to susceptible, have partial immunity against the virus and can recover after encountering the virus without passing through the infectious stage.

Unfortunately, in the presence of seasonal forcing, the oscillatory dynamics of the SIRC model are generally complex and rarely amenable to mathematical analysis. Modifying a recently developed approximation method for a seasonally forced epidemiological model [2], we identify a new threshold effect in the SIRC model. The threshold gives clear analytical conditions for predicting whether a given virus type will cause an epidemic outbreak in the following year, or there will be a 'skip' – a year in which the virus type fails to initiate an epidemic. The threshold is determined by the population's susceptibility and cross-immunity measured after the last outbreak and the rate at which new susceptible individuals are recruited into the population.

[1] Casagrandi, R., Bolzoni, L., Levin, S.A. & Andeasen V. The SIRC model and influenza *A. Math. BioSciences* 200:152-169 (2006).

[2] Stone, L., Olinky, R. and Huppert, A. Seasonal dynamics of recurrent epidemics. *Nature*. 446, 533-536 (2007).