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Human mobility and measles

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Abstract

Previous studies on measles revealed the importance of different mechanisms like external imports in disease free lands, seasonal forcing, or stochastic amplification in order to explain the dynamics observed in available datasets. We explore the relative importance of these mechanisms using a detailed geographical description of human mobility. We show the results of individual based simulations of a SIR and a SEIR model considering a gridded description of human settlements in the British Isles. Human mobility between different grid units is described by the radiation model [1]. We show that as the level of mobility is modified, the dynamics are described by multiannual, annual or biennial cycles.

Key words: stochastic amplification, human mobility, measles, SIR

1 Introduction

Geographical spread of measles has been extensively studied in recent years. As most infectious diseases, if measles propagates in low populated lands it is subject to extinction. In this case recurrent epidemics can occurr only due to imports from other countries [2]. In contrast, studies on measles incidence in England and Wales have shown that complex dynamics occur in high populated lands: here seasonality plays a pivotal role as it controls the epidemic cycles of the disease [3]. Recently, it has been observed that, for finite populations, the amplification of the stochastic fluctuations around a preferred frequency leads to sustained oscillations around the endemic equilibrium [4]. The amplitude and coherence of these fluctuations increases considerably when spatial or temporal correlations are taken into account [5, 6] and can become a source of recurrent outbreaks cycling with a characteristic temporal period. Our investigation explores the importance of these three mechanisms in presence of human mobility, using a detailed geographical description of human mobility.

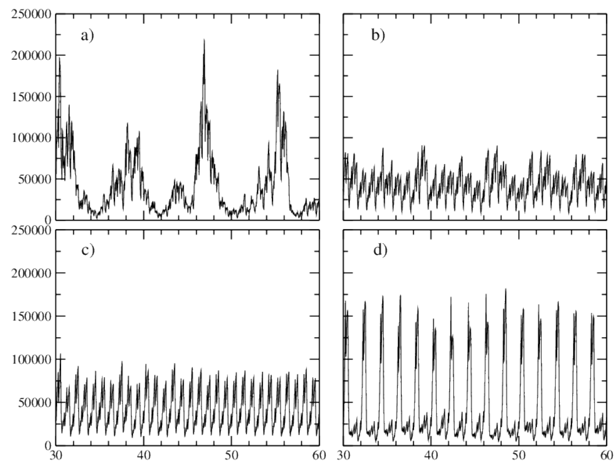

Figure 1: Time series of seasonally forced simulations for different values of the mobility ratio: (b) $N_c/N = 0.001$, (c) $N_c/N = 0.008$, (d) $N_c/N = 0.05$, (e) $N_c/N = 0.2$. Simulation with seasonality were performed with parameters as in the main text, resulting in $\langle \beta(t) \rangle = 1.4$.

2 Results

Our computer model describes the geographical distribution of human population using gridded maps from the Gridded Population of the World (GPW) [7] database. Each grid element of the map is considered a well mixed population, and the disease will evolve according to a given epidemiological model. The population is simulated using individual agents and each individual can commute to different grid elements where he can eventually be infected or transmit the disease, thus participating to large-range transmission of the disease. This movement of indviduals is described by the *radiation model* [1]. The model depends on only one parameter, the mobility ratio, which can be estimated from available data for human mobility. The disease model we use here is the compartmental SIR and SEIR model with multiple infective and exposed classes, parametrized for measles [3, 8] with seasonality described by term-time forcing and constant population size. The ratio N_c/N of commuters with respect to the total population controls human mobility and can be estimated using census data available from the Office of National Statistics of the United Kingdom [9], however we can tune it to different values to explore its influence on the dynamics of the disease.

The global behavior for the British Isles area for different values of N_c/N is shown in Fig. 1. As can be inferred from the figure, the dynamics change when increasing the mobility ratio. For $N_c/N = 0.001$ (a) the dynamics exhibits less frequent and more temporally

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wide outbreaks. For mobility ratio 0.008(b) and 0.05 (c), the frequency of the outbreaks is annual, while for 0.2 (d) is biennial. This suggest that globally the dynamics is determined by the level of mobility of individuals between different locations.

When we look at the city level, we identify three regimes. First, for high populated cities, the dynamics is mainly driven by the seasonal forcing, imports from outer regions are less important. For low populated cities instead the observed frecuency of the outbreaks is influenced by the mobility ratio, and an appropiate level of mobility must be achieved in order for recurrent epidemics to be sustained. For intermediate population levels, an adequate level of mobility is needed for the epidemic to be sutained, but due to the appropriate population size the stochastic fluctuations are amplified.

Simulations with SIR and SEIR are qualitatively equivalent for a number of infective and exposed classes greater than one.

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