Epidemics with Flute

Christoph Becker and Richard Bower

Two approaches to Epidemiological models

- Differential equations averaging over the source population
  - Bernard's seminar
  - SIR models are based around equations like:

$$\frac{dS}{dt} = -\beta \, S \, I$$

- Agent based models
  - Follow individuals in the population
    - They meet, infect each other and become sick.
    - Possible to follow the life history of an individual
    - Allow for complex behviour and geography.

What is Flute?

- An open source Agent based epidemiological model
- Appealing features:
  - Open and down-loadable
  - Source code contains comment
  - Written in C++ (fortran-style)
- Draw-backs
  - Set up for USA
  - Set up for Influenza
  - Limited options for response

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FluTE, a Publicly Available Stochastic Influenza Epidemic Simulation Model

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Abstract

Mathematical and computer models of epidemics have contributed to our understanding of the spread of infectious disease and the measures needed to contain or mitigate them. To help prepare for future influenza seasonal epidemics or pandemics, we developed a new stochastic model of the spread of influenza across a large population. Individuals in this model have realistic social contact networks, and transmission and infections are based on the current state of knowledge of the natural history of influenza. The model has been calibrated so that outcomes are consistent with the 1957/1958 Asian A(H2N2) and 2009 pandemic A(H1N1) influenza viruses. We present examples of how this model can be used to study the dynamics of influenza epidemics in the United States and simulate how to mitigate or delay them using pharmaceutical interventions and social distancing measures. Computer simulation models play an essential role in informing public policy and evaluating pandemic preparedness plans. We have made the source code of this model publicly available to encourage its use and further development.

Citation: Chao DL, Halloran ME, Obenchain VJ, Longini IM, Jr. (2010) FluTE, a Publicly Available Stochastic Influenza Epidemic Simulation Model. PLoS Comput Biol 6(1): e1000656. doi:10.1371/journal.pcbi.1000656

Editor: Angela R. McLean, University of Oxford, United Kingdom

Received July 17, 2009; **Accepted** December 22, 2009; **Published** January 29, 2010

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Funding: This work was supported by the National Institute of General Medical Sciences MIDAS grant U01-GM070749, the National Institute of Allergy and Infectious Diseases grant R01-AI32042, and the Los Angeles County Department of Health. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

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How flute works

- Input census data “tracts”
  - Population, workers, work flows between tracts
- Populate the “world”
  - Assign people to
    - Tract
    - Community
    - householdCluster
    - SchoolGroup
    - Family
    - Age group
    - Place of work
- These assignments determine how strongly people interact and day and at night

To run the model:

- Loop over the infected communities
  - Infect susceptible people
    - Depends on a product of factors
      - Viral load of infected
      - extent of contact
      - Susceptibility of other person
- Some infected people withdraw if…
  - They are ill
  - Someone in their family is ill
  - Schools are closed
  - There is a lockdown
- Send a fraction on random travels

Adapting census data to the uk

- Over to Christoph…

Adding viral data for Covid-19

- Viral load (and how many days?)
  - {0., 4.0, 10., 9.0, 6.2, 3.8, 2.2, 1.2, 0.66, 0.35, 0.18, 0.09, 0.05, 0.02} (based on He et al)
  - These numbers are normalised by an R0 factor
- An up weighting for symptomatic people
  - Factor 2
- Incubation period distribution
  - {0.01, 0.05, 0.18, 0.38, 0.54, 0.7, 0.87, 0.9, 0.95, 1.0}
- Fraction that become symptomatic
  - 0.58. (Levezzo et al)
- A age dependent susceptibility
  - Not used at present

But epidemiology is really about mixing…

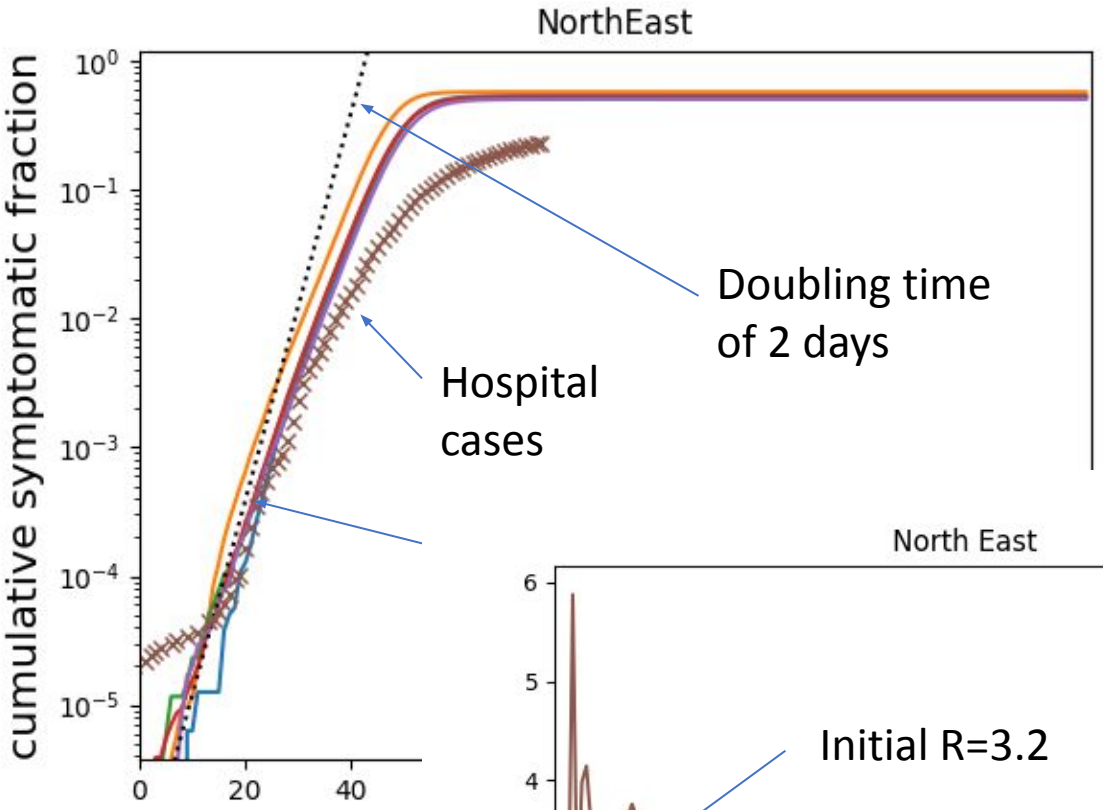
			0-5, 5-18, 19-29, 30-64,64+
work		cpw	0.05
community		cpcm	0.0000109, 0.0000326, 0.000087, 0.000087, 0.000174
neighbourhood		cpnh	0.0000435, 0.0001305, 0.000348, 0.000348, 0.000696
Household cluster	From adult	cphca	0.025, 0.025, 0.037, 0.037, 0.037
	From child	cphcc	0.08, 0.08, 0.037, 0.037, 0.037
family (adult)	From adult	cpfa	0.25, 0.25, 0.37, 0.37, 0.37
	From child	cpfc	0.8, 0.8, 0.37, 0.37, 0.37
			none, high school, middle school, elementary (2), day care (4), play group
school		cps	0.0, 0.0252, 0.03, 0.0348, 0.0348, 0.12, 0.12, 0.12, 0.12, 0.28

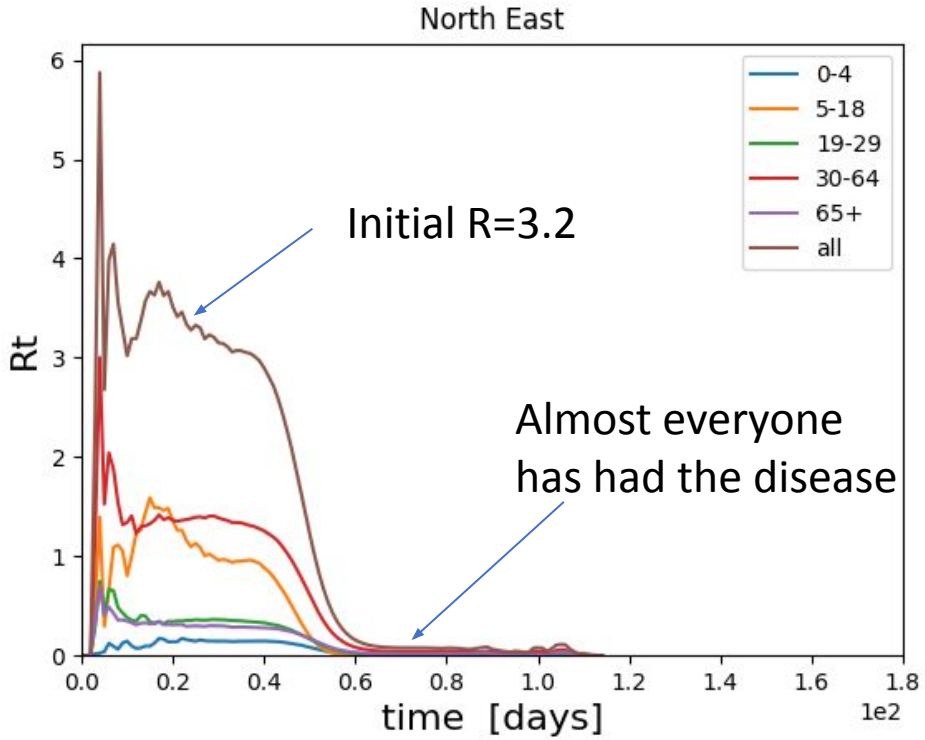
An additional scaling is applied for day vs night

Travel probability: 0.0023,0.0023,0.0050, 0.0053,0.0028

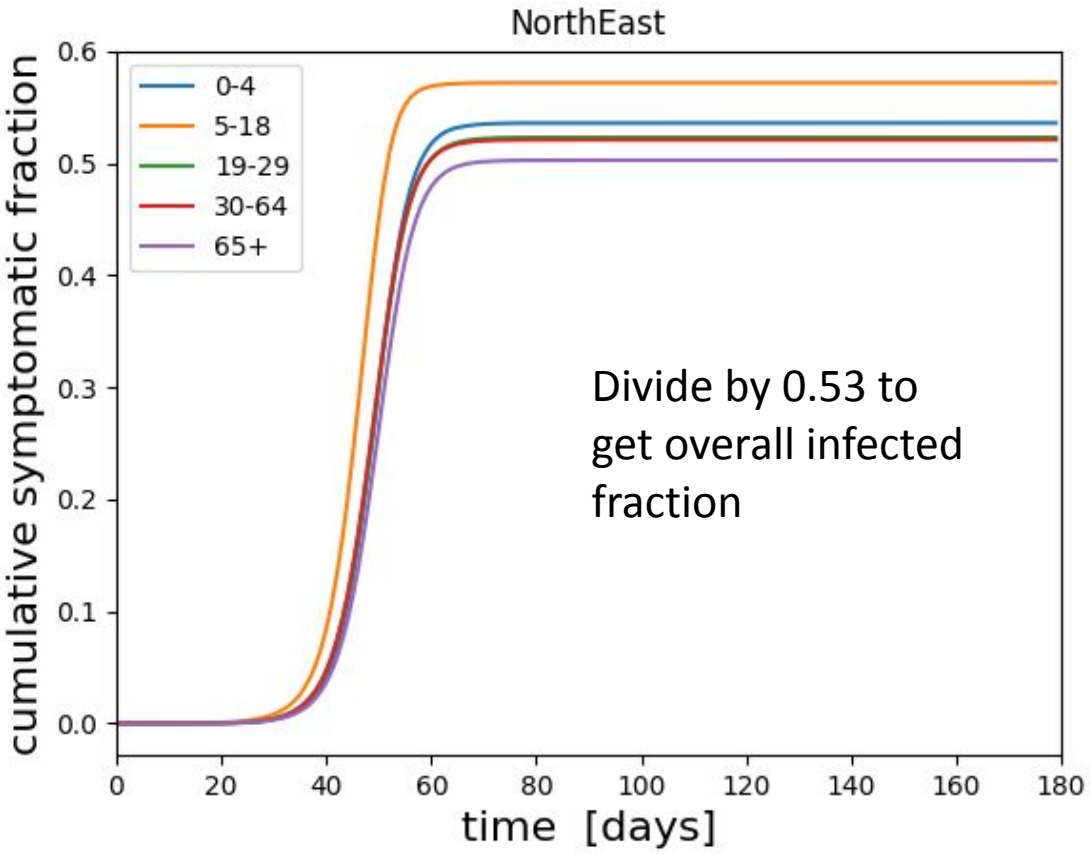
Some results…

- Some results for the NorthEast (no response)
- Look at:
  - Number of ill people at one time
  - How many go ill overall
  - Effective value of beta and R0

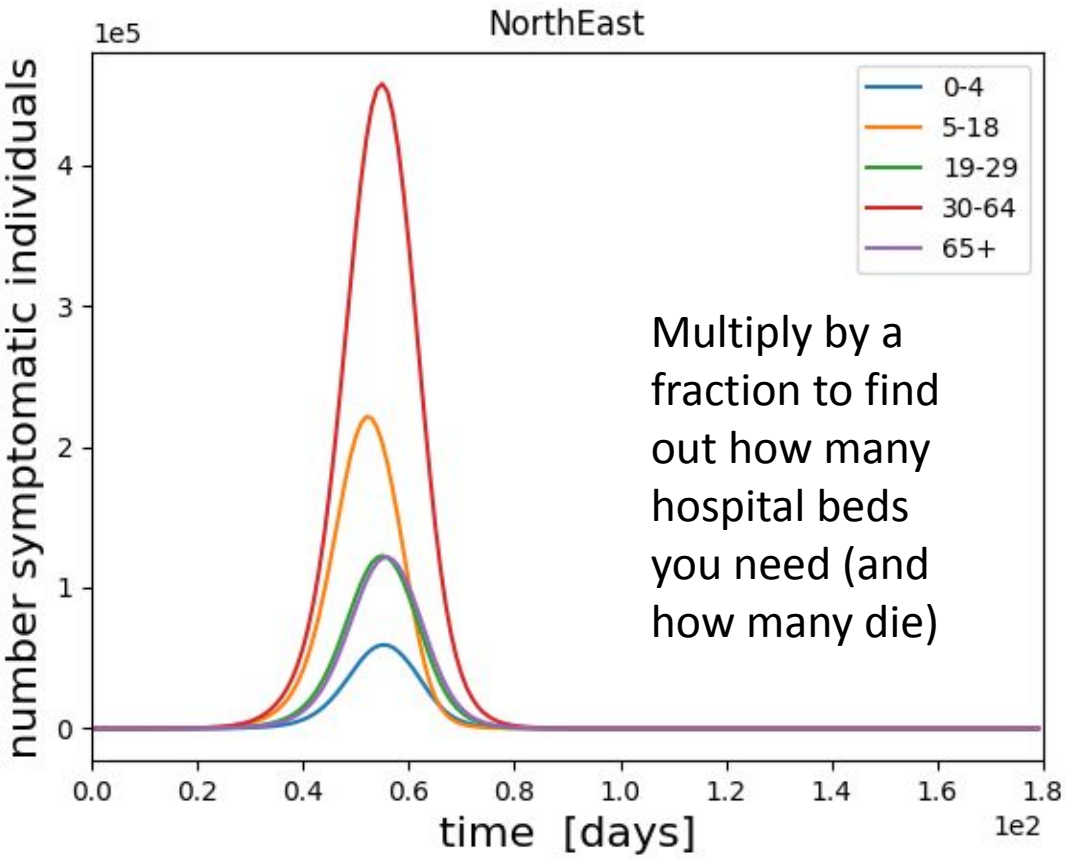




How bad can it be??



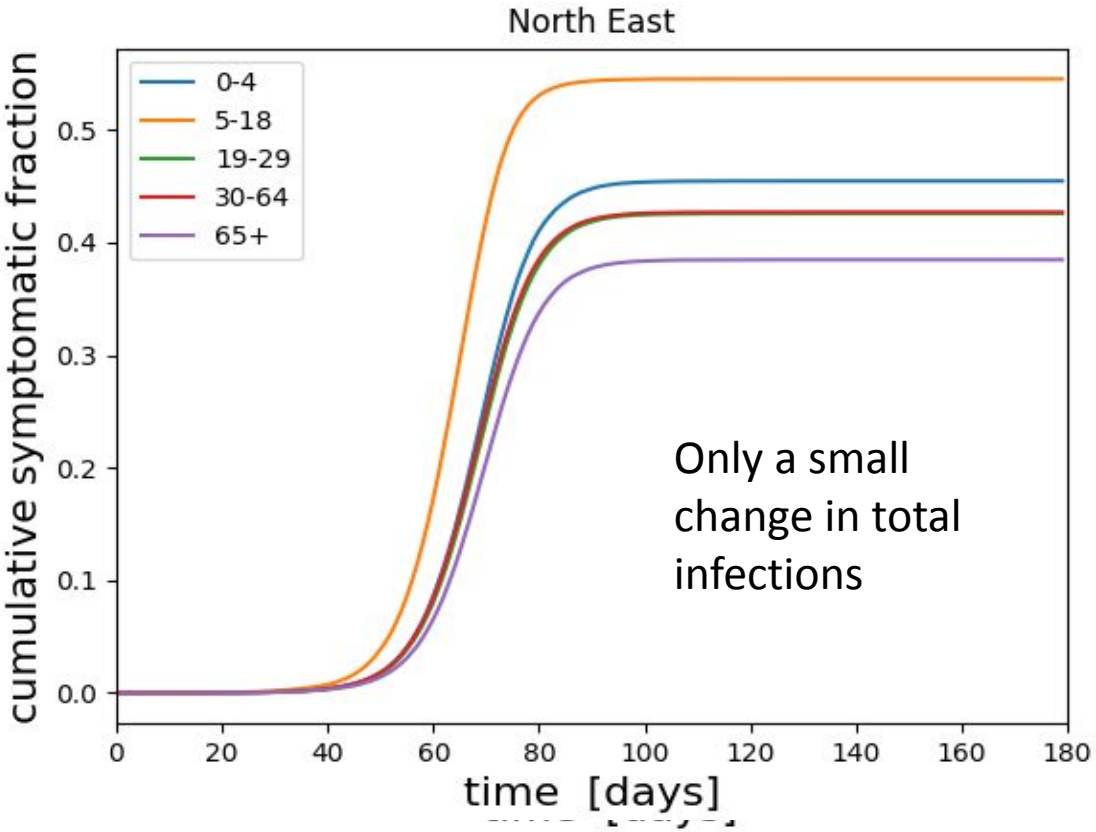
Divide by 0.53 to get overall infected fraction

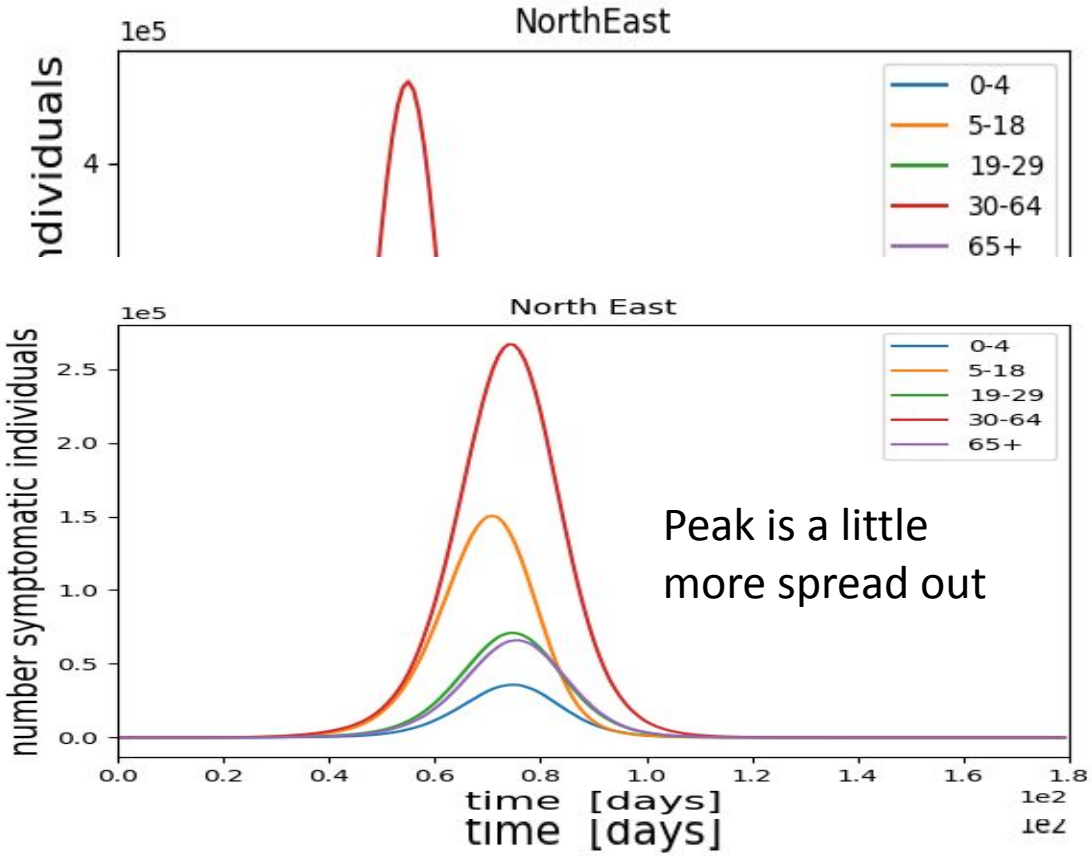


Multiply by a fraction to find out how many hospital beds you need (and how many die)

How bad can it be??

Assume R0 = 2.3 ??

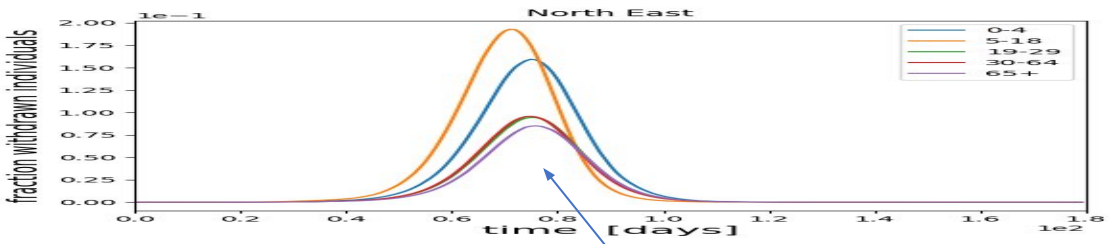




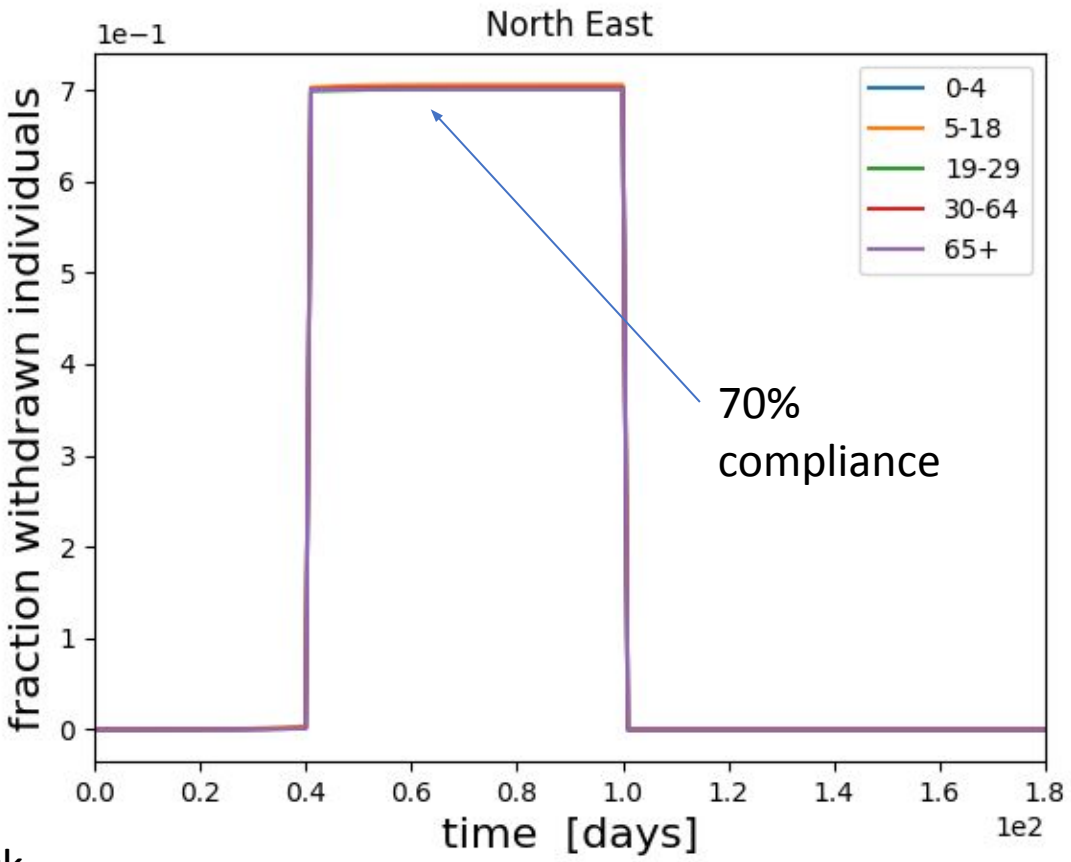
Something must be done!

During lockdown, people withdraw voluntarily:

- no work,
- no travel
- No schools
- Quarantive for family members

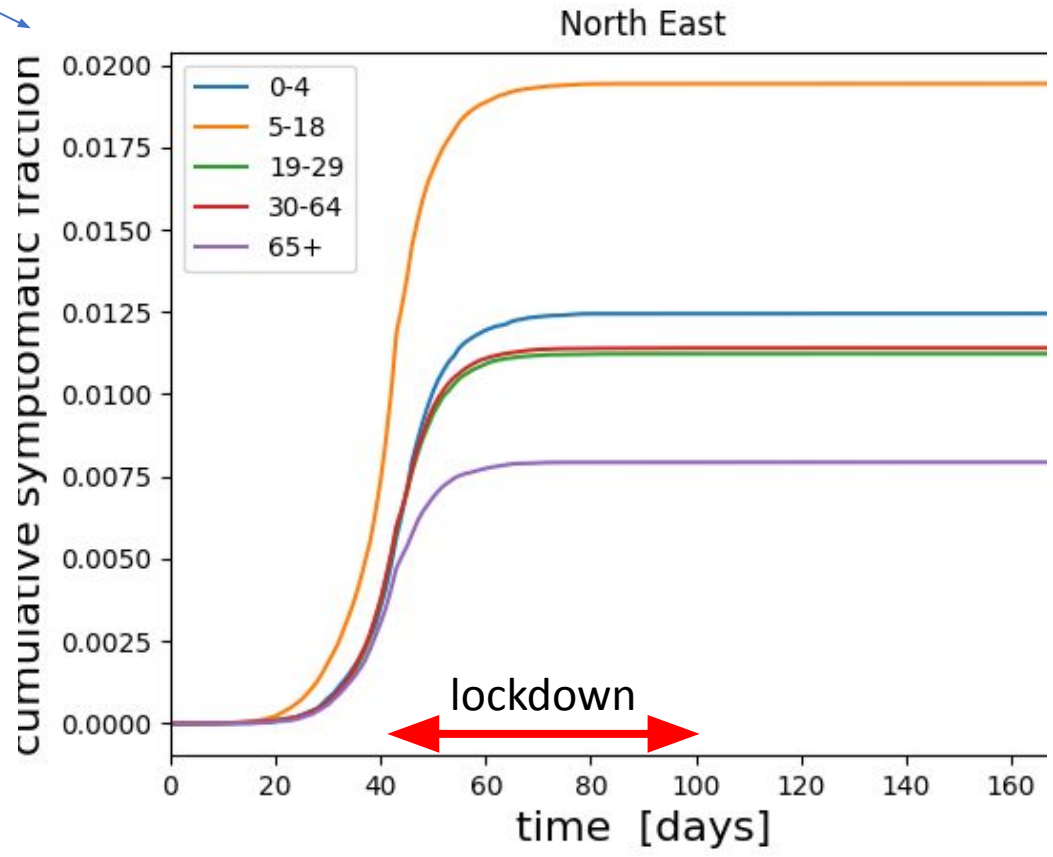


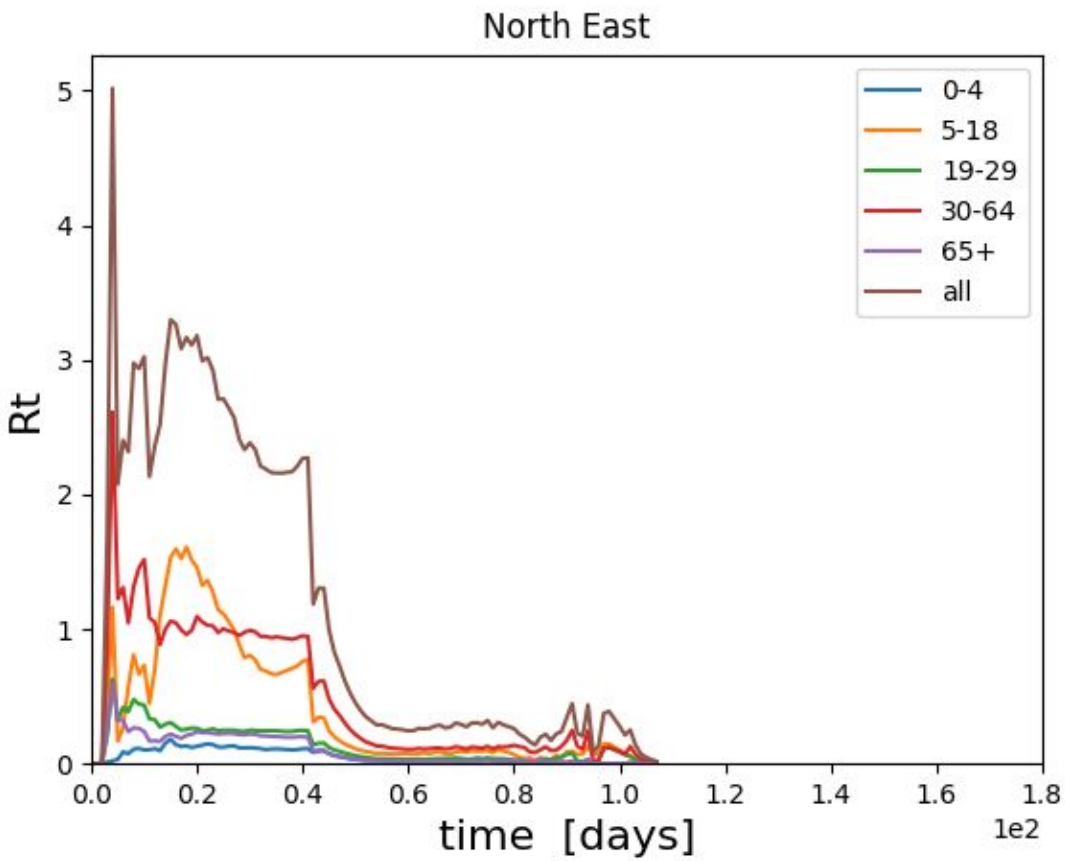
Without lockdown, only sick people withdraw



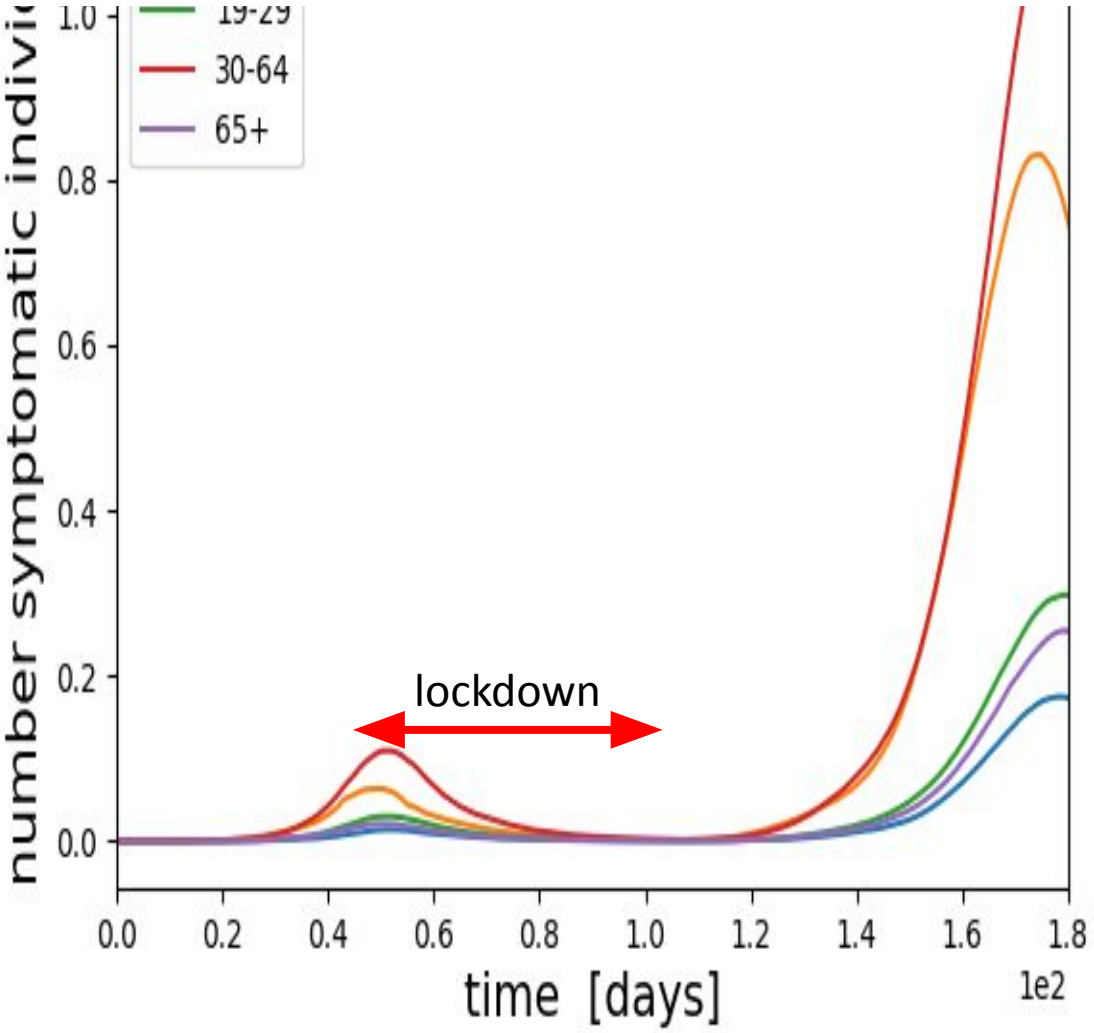
Effect of lockdown

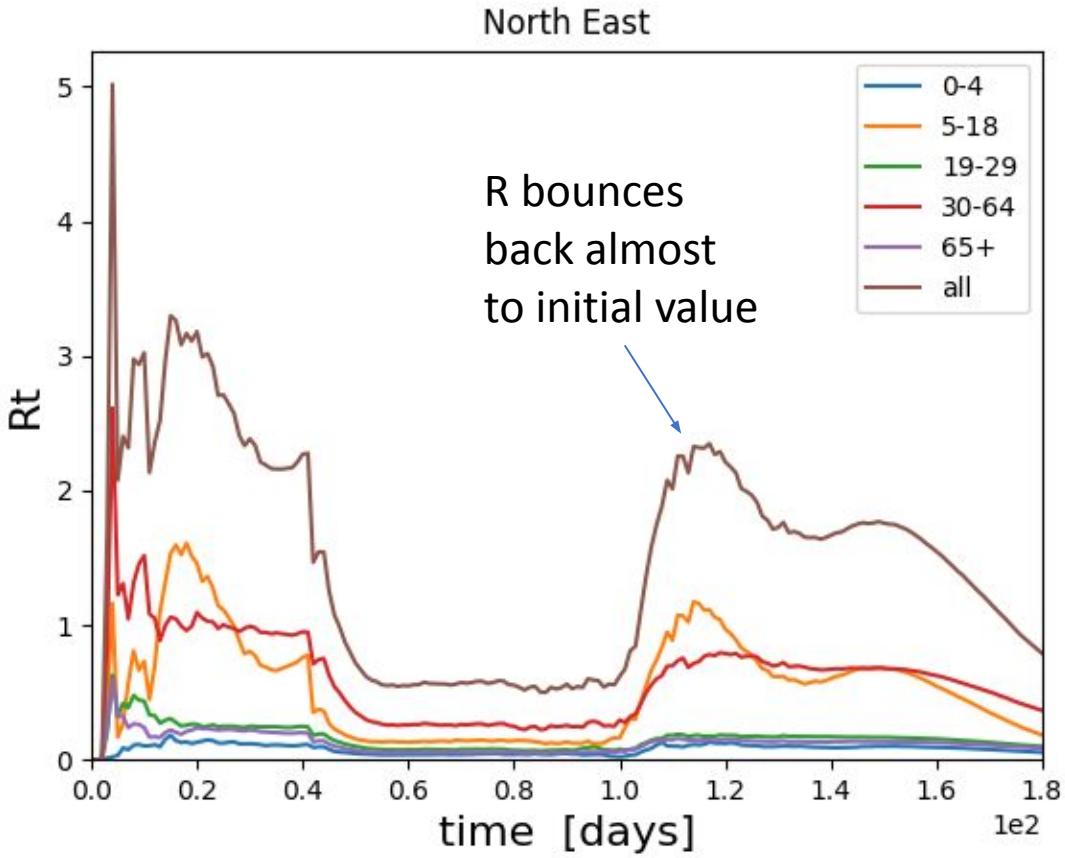
Very small fraction





Effect of lockdown (if 50% compliant)





Geography

- The advantage of Flute is that it contains geographic information
- We can study the spread across the UK
  - How fast does disease move
  - What transports it across the UK
  - Does geography help “slow the peak”?
  - Can this be used to make partial lockdown more effective?

Spread across England+Wales

- Map of number of symptomatic cases on a given day.
- (renormalised each day)

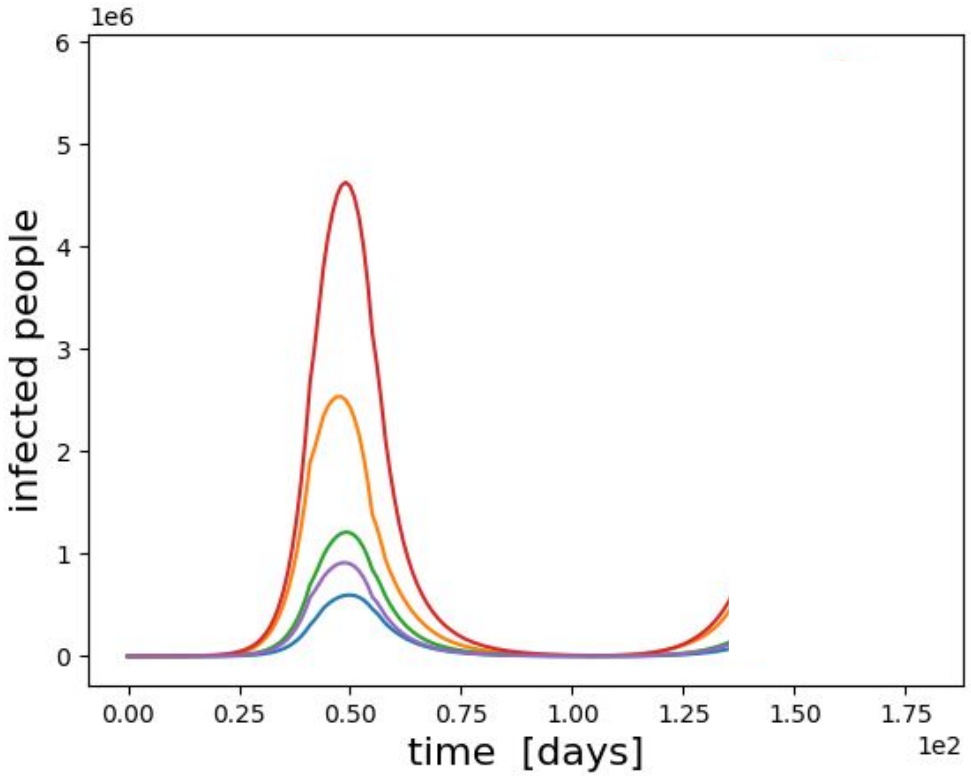
Spread across England+Wales

- Map of number of symptomatic cases on a given day.
- (renormalised each day)

This version shows effect of banning travel… now disease travels by commute and schools…

Effect of lockdown

- Effect of lockdown (day 40 then release on day 100)



Conclusions

- Flute seems to work as a viable geographic model
- Completed adaptation to
  - UK census data
  - Coronavirus
- Implemented
  - Lockdown and release
  - Seeding following initial data

- More testing needed
  - Detailed comparison to SIR
  - “sense check” results for age and geographic dependence
  - Does geographic evolution match data?