Introducing JUNE
an open-source epidemiological simulation

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Outline

1. introduction: individual-based models
2. introducing JUNE
3. results for the first wave(s) in England
4. some example projections (no fit to data)
5. a spin-off: Cox's Bazaar Refugee Operation
6. conclusions & outlook

June Almeida

discovered Corona Virus (1964)

introduction:

individual-based models

agent-based models for epidemics: construction principle

- track disease progression through each individual

  (thus populations become highly heterogeneous by health status during simulations),
- track contacts of individuals in social environments and geographies
- add explicit rules for disease transmission and impact
- agents are individuals: $\longrightarrow$ **individual-based model**
- need to construct:

population & social environment
+
disease transmission & health impact

most famous example: Imperial College model

N.Ferguson et al., "*Strategies for containing an emerging influenza pandemic in Southeast Asia*", Nature 437 (2005) 209-214
N.Ferguson et al., "*Strategies for mitigating an influenza pandemic*", Nature 442 (2006) 448–452

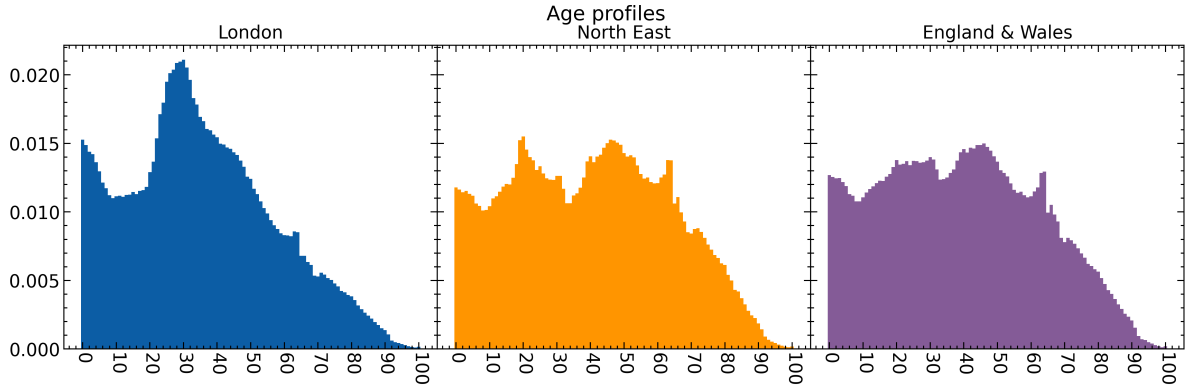
- population model:
  - distribute population in age & sex according to national distributions
  - distribute population according to national population density
- social environments:
  - four relevant environments: household, company, school, other
  - household, company, and school sizes and composition distributed according to nation-wide distribution
  - "other" captures all contacts in the closer or wider community:
    - → venues such as: shops, gyms, pubs, ...
    - → activities such as visiting friends & relatives, travel, ...
    - → distribute them according to a $1/(r + r_0)$-law w.r.t. place of residence

June

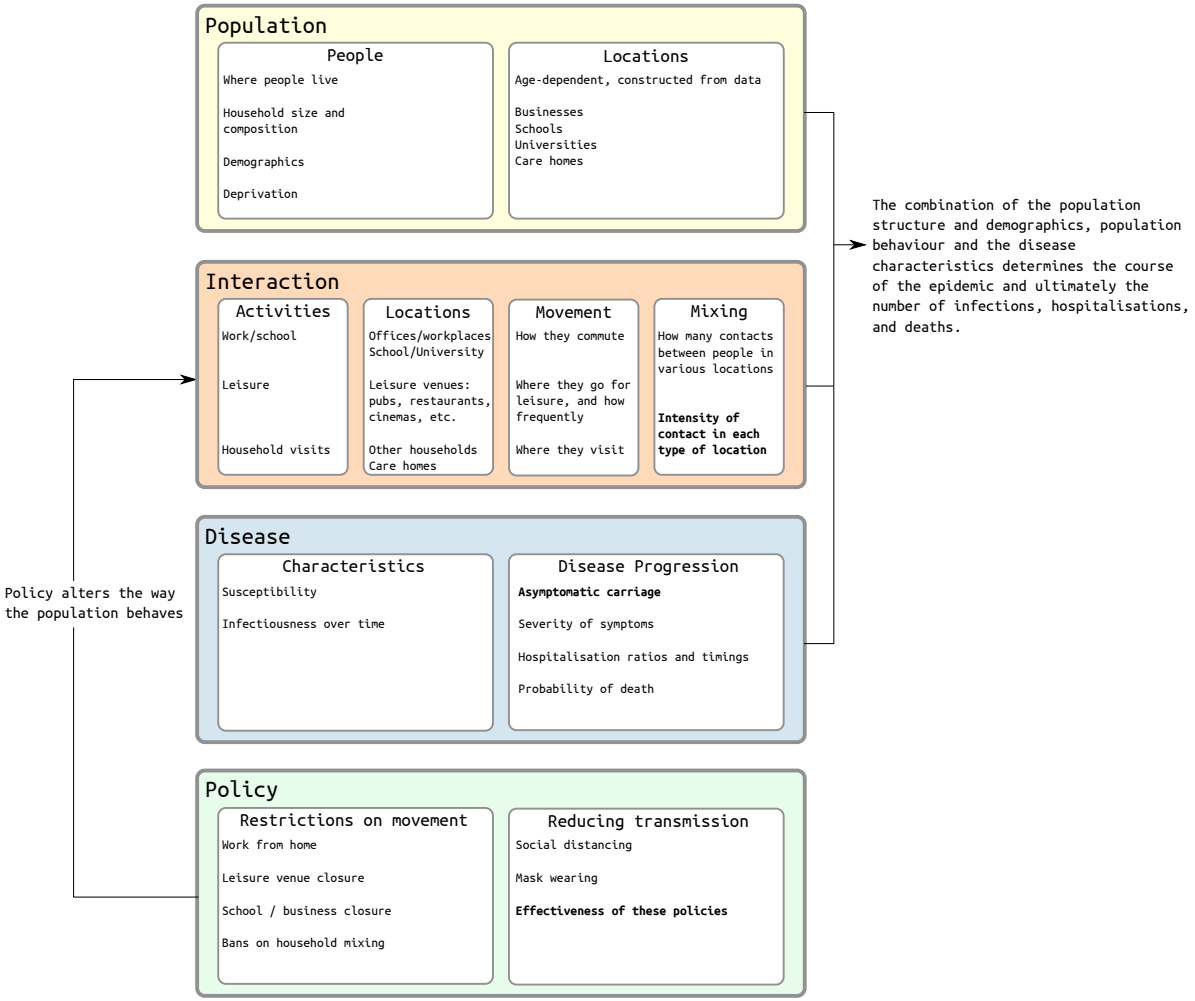
motivation: why granularity matters

- impact of COVID=19 highly age-dependent
  $\longrightarrow$ **need geographical granularity for regional planning**

(coincidence: Durham hosts & maintains England & Wales census data of past decades)



JUNE simulation content - summary

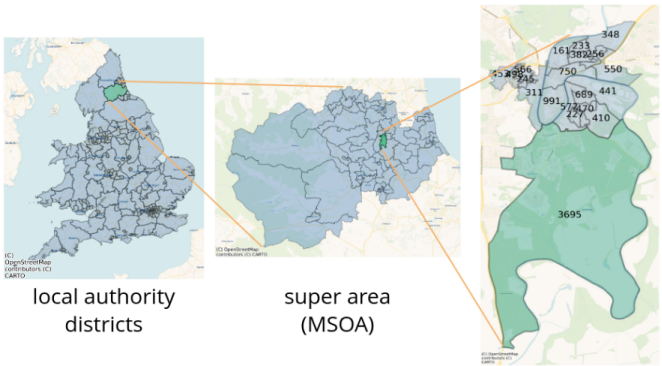


inputs: demographics

- last census (2011)

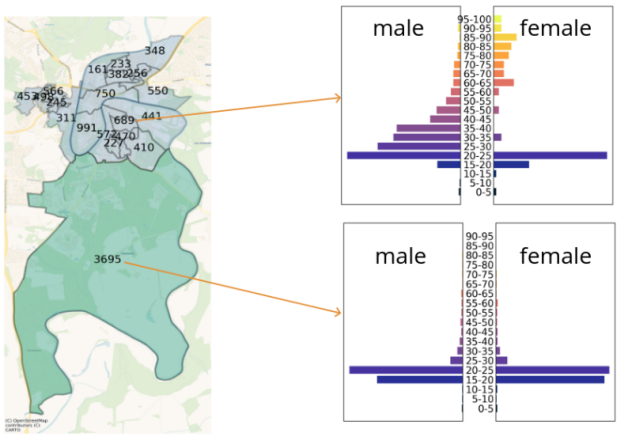
  (data freely available from Office for National Statistics)

- hierarchical data structure



- OA's with $\sim$ 250 residents, with similar characteristics

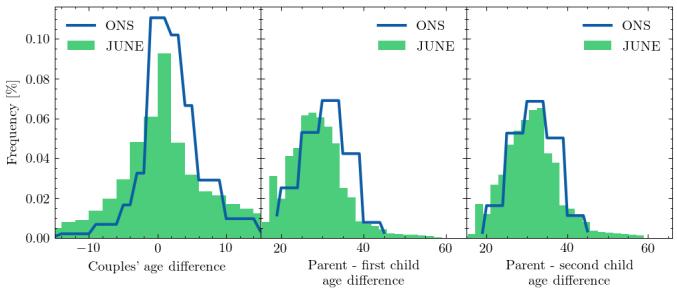
- build virtual population in OA: age, gender, ethnicity, deprivation index
- example: Durham



virtual households

- correct compositions important: primary place for infections
- household composition in 20 categories at OA level

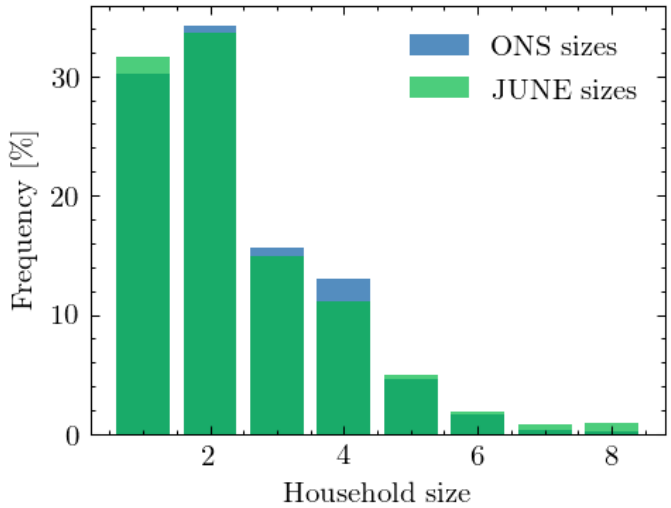
(children, young adults, adults, old adults)



- also: communal facilities

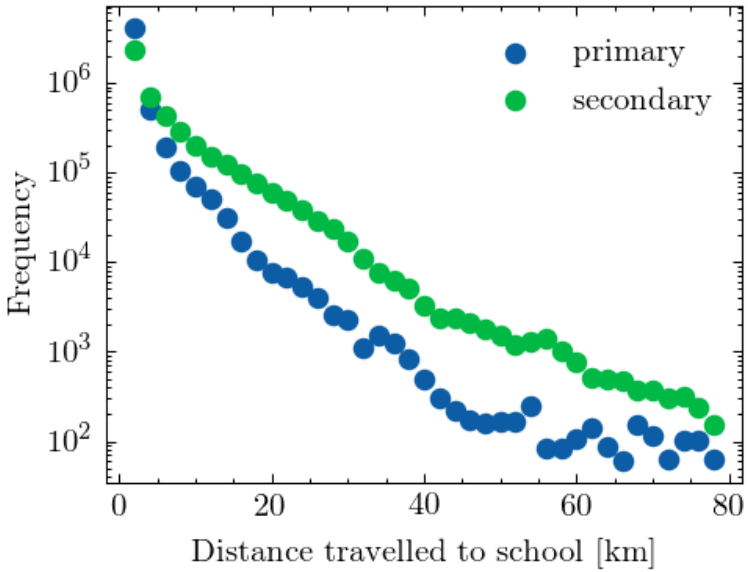
(carehomes)

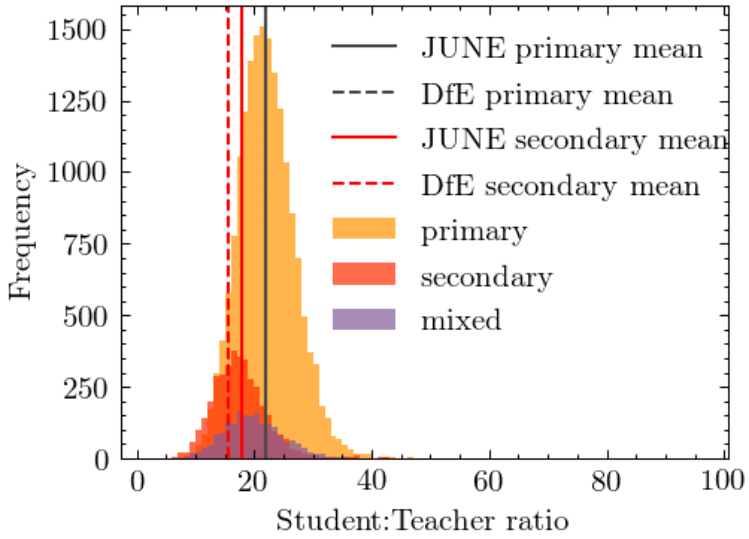
- further test: interplay with social mixing
- example: North-East England



virtual schools

- information about schools: age range of children and locations
- send kids to nearest age-appropriate structure
- could modulate this with school sizes, if necessary

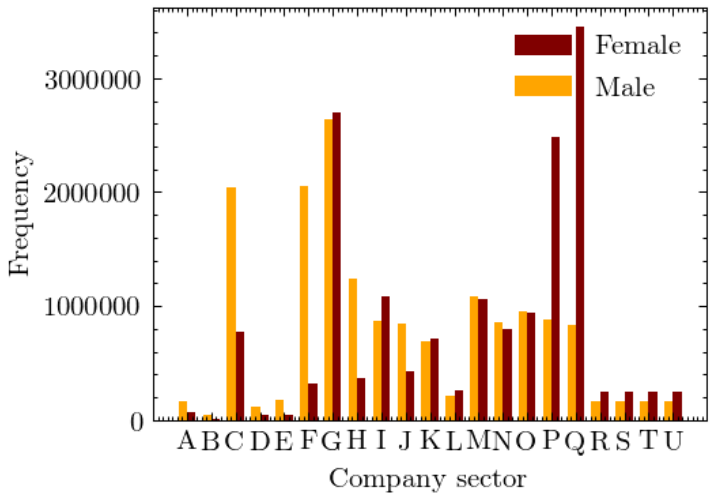


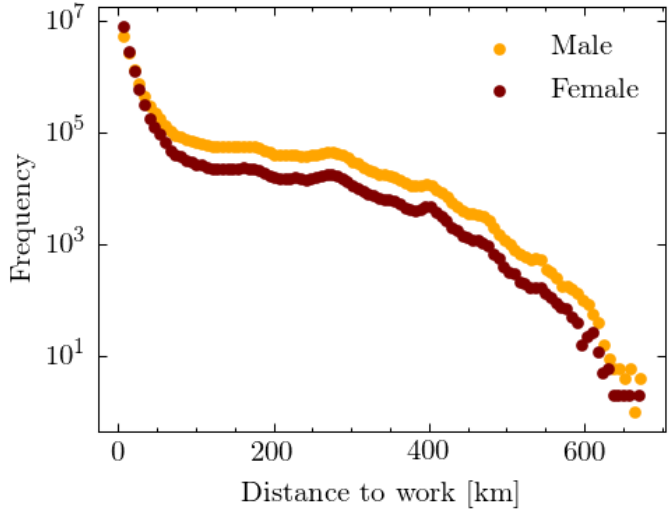


work & virtual companies

- workers and companies in $\sim$ 20 macro-sectors at MSOA level
- know age/sex distribution in sectors nation wide
- distribute workers over companies (we know their sizes in bins)

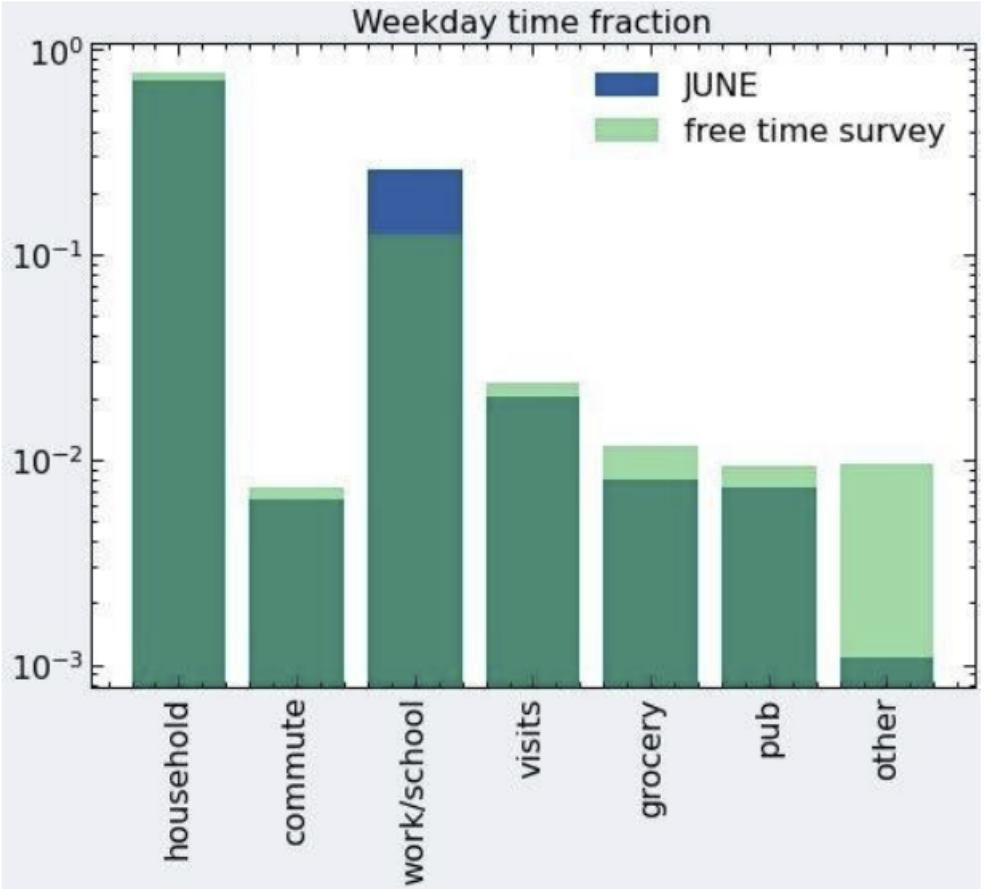
  (construct a big origin-destination matrix & optimise)
- information about commute mode: public vs. private





daily activities: average time budget

- compare our simulation with data from ONS
- average time spent per day in different activities



social mixing matrices

- move on to the environment for the interactions
- use social mixing matrices from POLYMOD and BBC Pandemics project

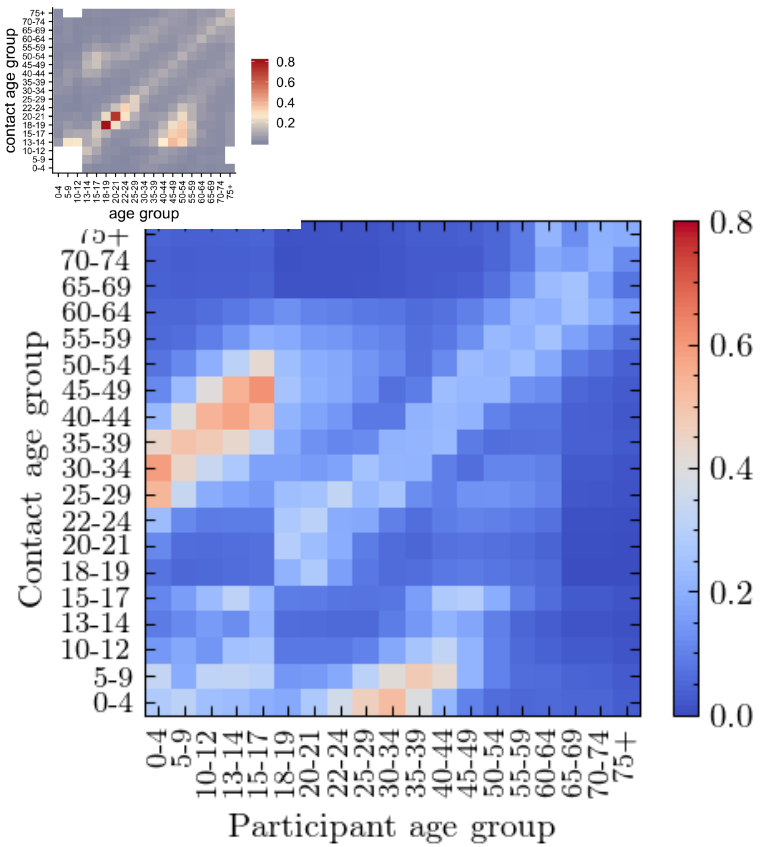
  J.Mossong et al., PLoS Med 5(3) e74, https://doi.org/10.1371/journal.pmed.0050074;
  P.Klepac et al., https://www.medrxiv.org/content/10.1101/2020.02.16.20023754v2

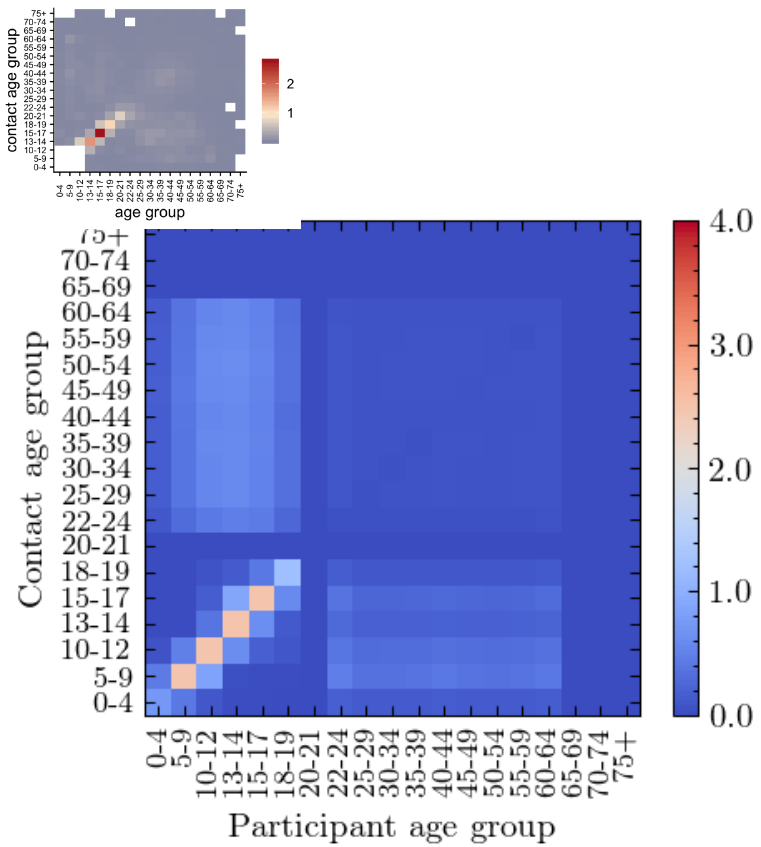
- denote number of contacts of person with age i with person of age j
- somewhat tricky format: averages over full population
  $\longrightarrow$ have to normalise it to our fractured social environment
  $\longrightarrow$ interplay with household sizes etc. (may have to be fitted?)

JUNE output

- example: household (left) & schools (right) (BBC results as inlays)
- broad agreement with input from surveys: interesting closure test

(in JUNE contacts also depend on composition of environment)





disease transmission

- probabilistic process:

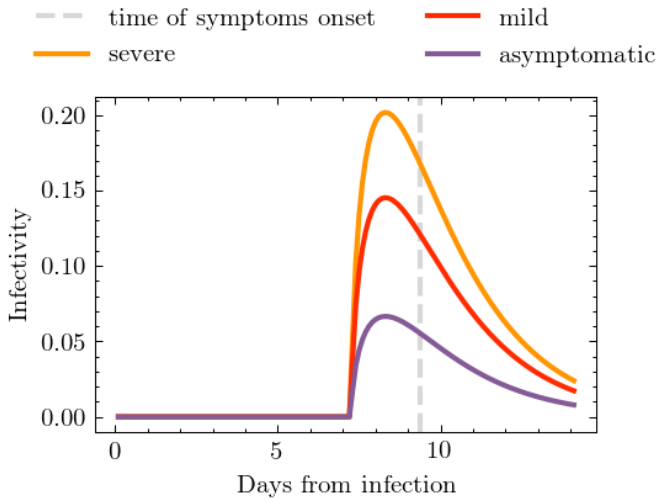
$$\mathcal{P}_{\int}(t,\, t+\Delta t) \;=\; 1 - \exp\left[-\psi_s \beta_{si}^{(E,g)} \int_t^{t+\Delta t} \mathrm{d}t' \sum_{i \in g} I_i(t')\right] ,$$

- ψ_s is susceptibility (reduced for children)
- $\beta_{si}^{(E,g)}$ is constant "closeness" in environment E, modulated by contact matrix:

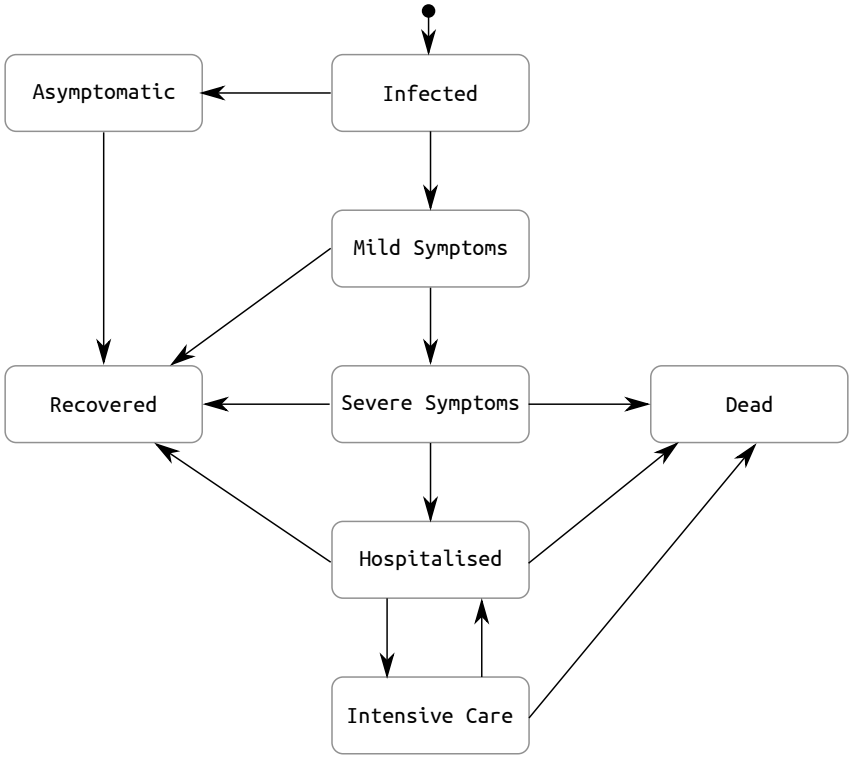
$$\beta_{si}^{(E,g)} = \beta^E \cdot \frac{\chi_{si}^{(g)}}{N_g}$$

with size of group N_g

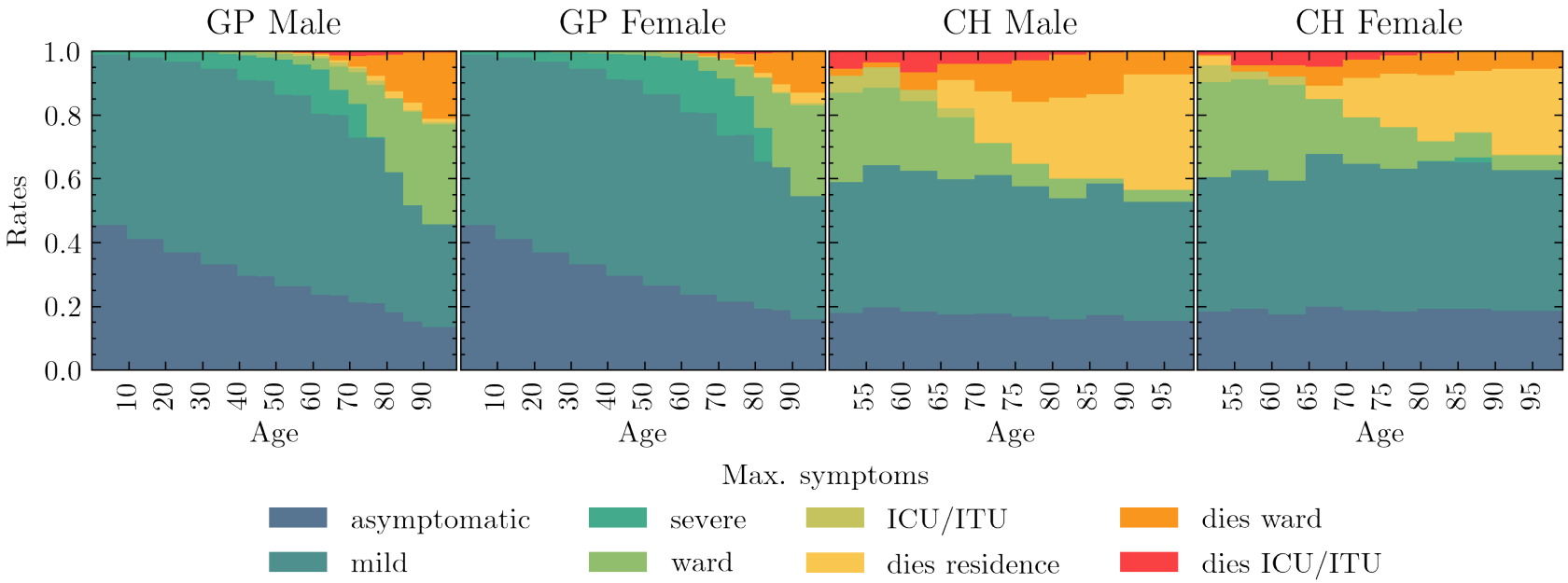
- $I_i(t')$ is infectiousness profile



outcomes of infection



- this was a tiring data-mining exercise with inconsistent and often contradictory data
- extra difficulty: include care homes (CH) vs. general population (GP)



policies

- below a list of relevant policies for results
- realised by modifications of β (e.g. social distancing) or by making activities unavailable

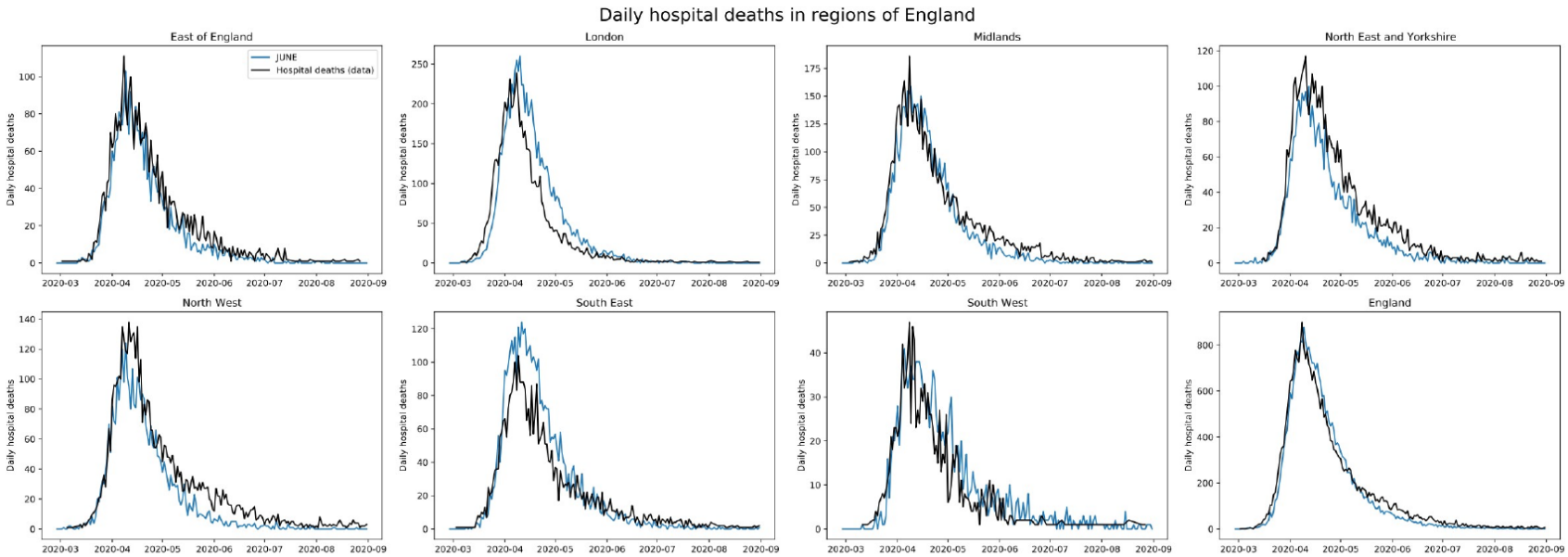
Date (dd/mm/yy)	Policy
12/03/20	case isolation at home
16/03/20	voluntary household quarantine, work from home, avoidance of leisure activities, encourage social distancing, stop all non-essential travel & contact, shielding of over 70's
20/03/20	closure of schools and universities
21/03/20	closure of leisure venues
11/05/20	multiple trips outside are allowed in England only
13/05/20	encourage to go back to work while distancing
01/06/20	meeting in groups of up to 6 outside allowed, shielding of over 70s relaxed, school reopening for Early Year and Year 6 students
13/06/20	'support bubbles' allowed
15/06/20	school reopening for Year 10 and 12 students for face-to-face support
04/07/20	leisure venues allowed to reopen, household-to-household visits permitted along with overnight stays
24/07/20	Mask wearing compulsory in grocery stores
01/08/20	shielding is paused, 'Eat Out to Help Out' scheme introduced
31/08/20	'Eat Out to Help Out' scheme ends
01/09/20	schools and Universities allowed to reopen, 'Rule of 6'
14/10/20	Tiered local lock-down system introduced

JUNE results for the first wave

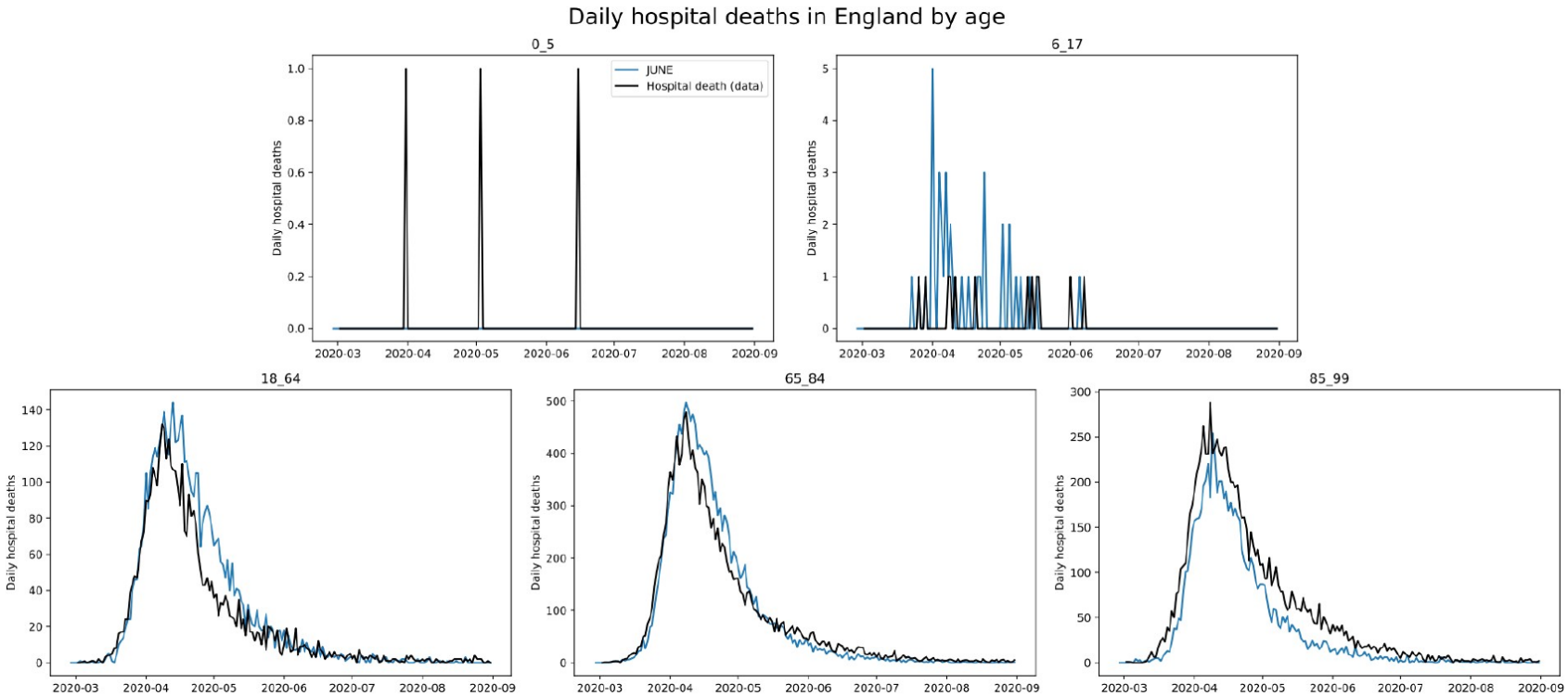
JUNE results

- below a selection of JUNE results for the 1^{st} wave in England
- some aspects of the code changed in the meantime:
  - seeding of infections: variants, clusters
  - added vaccination protocols and uptakes
  - added gyms as leisure venues
  - take into account ethnicity in household compositions

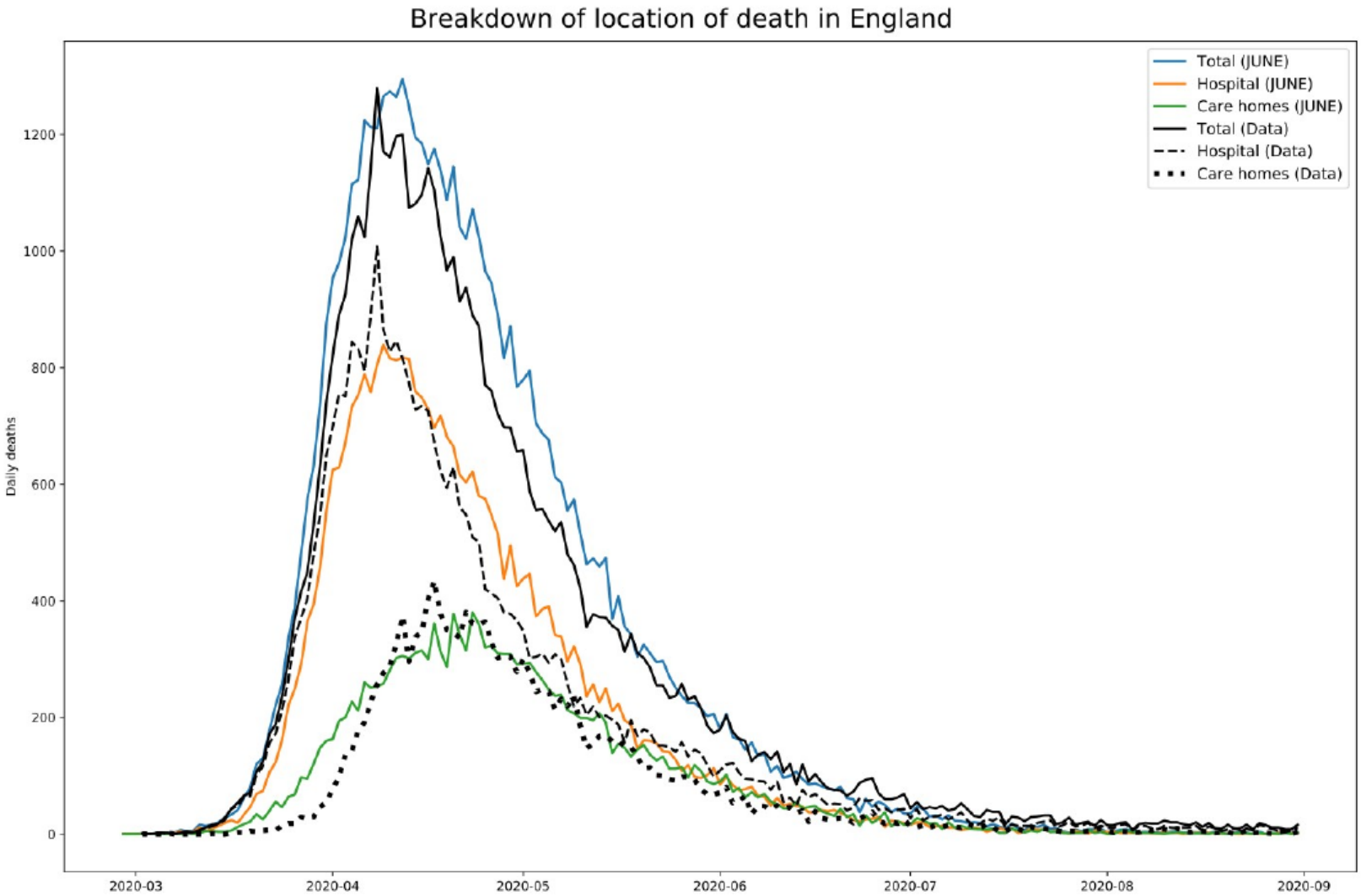
- 1^{st} wave: deaths in hospitals - regional distribution



- 1^{st} wave: deaths in hospitals - age distribution

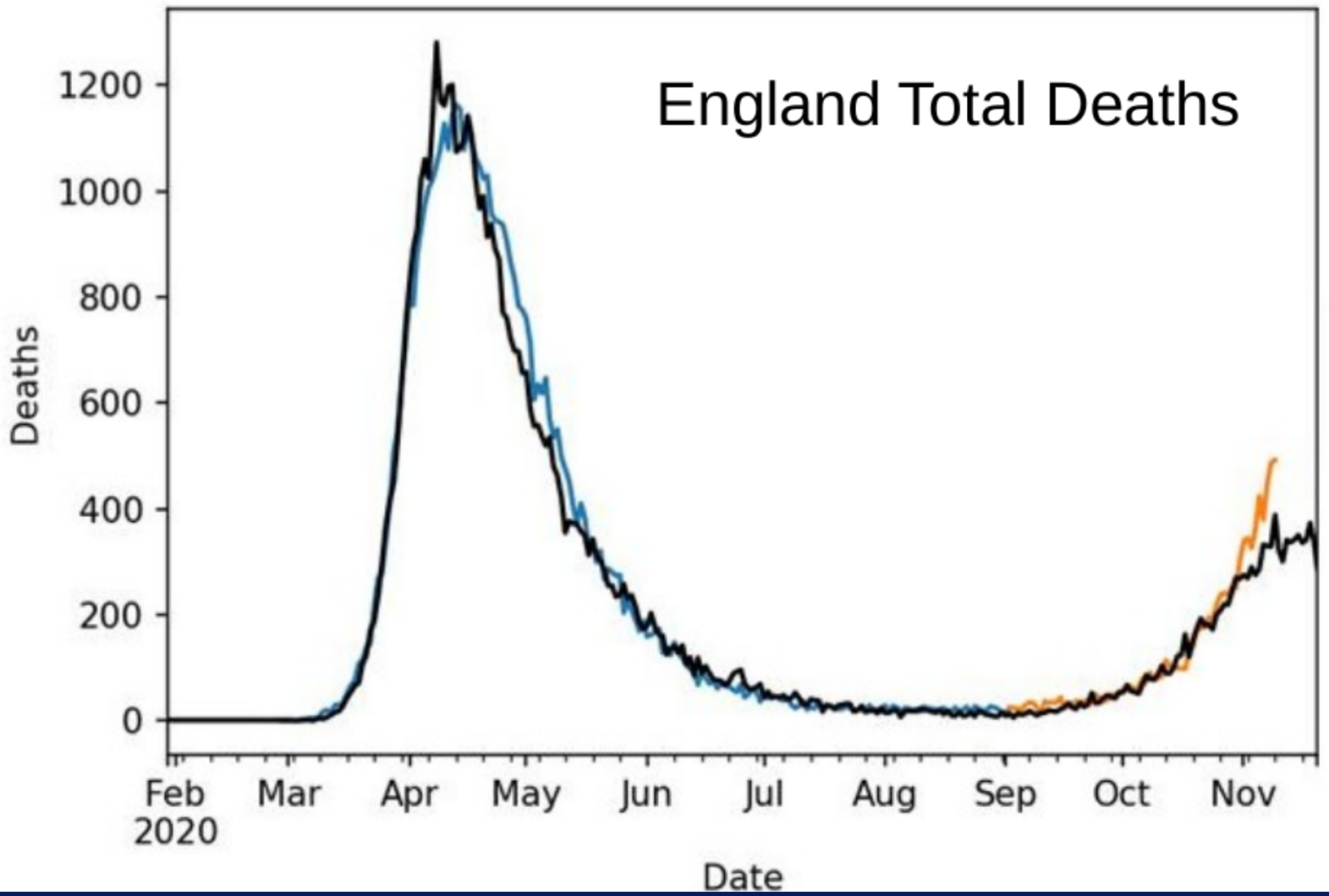


- 1^{st} wave: all deaths - distribution of location



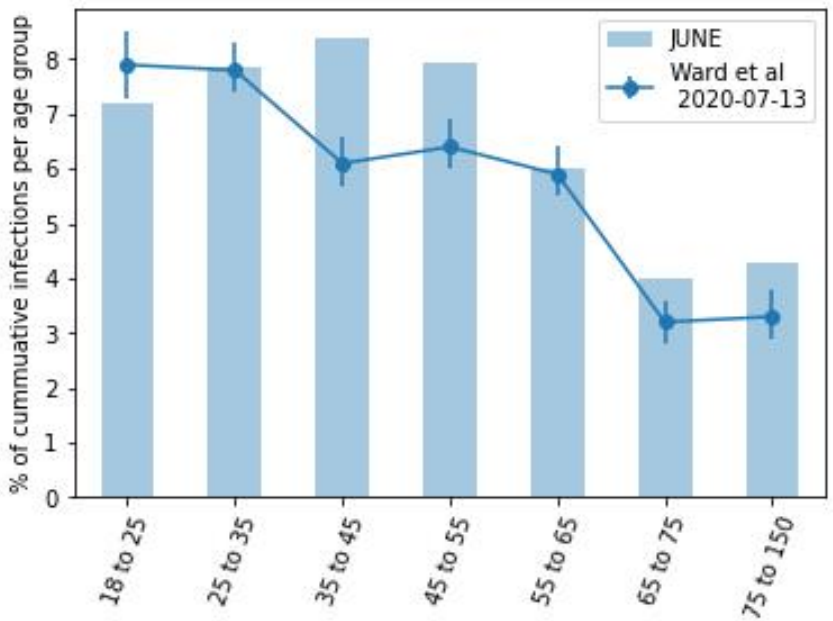
- extrapolation to second wave from September 1st

fitted parameters from first wave only!

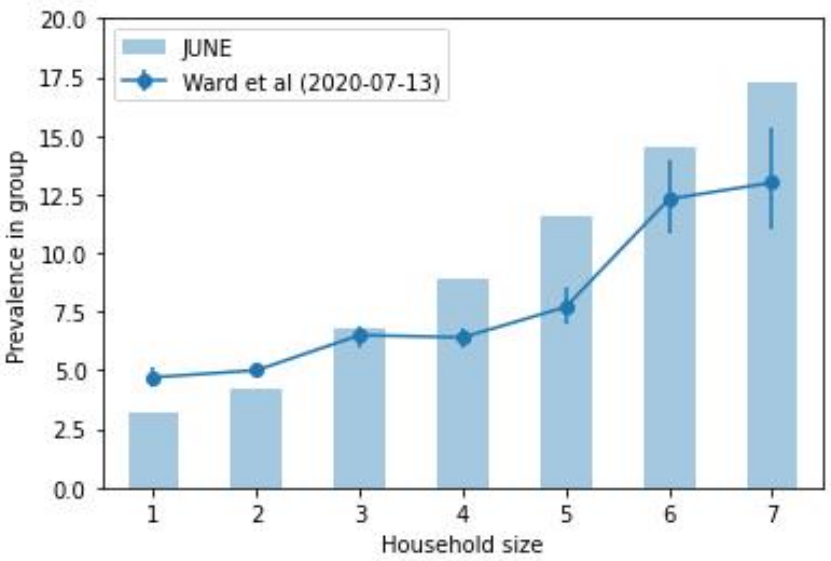


social imbalances

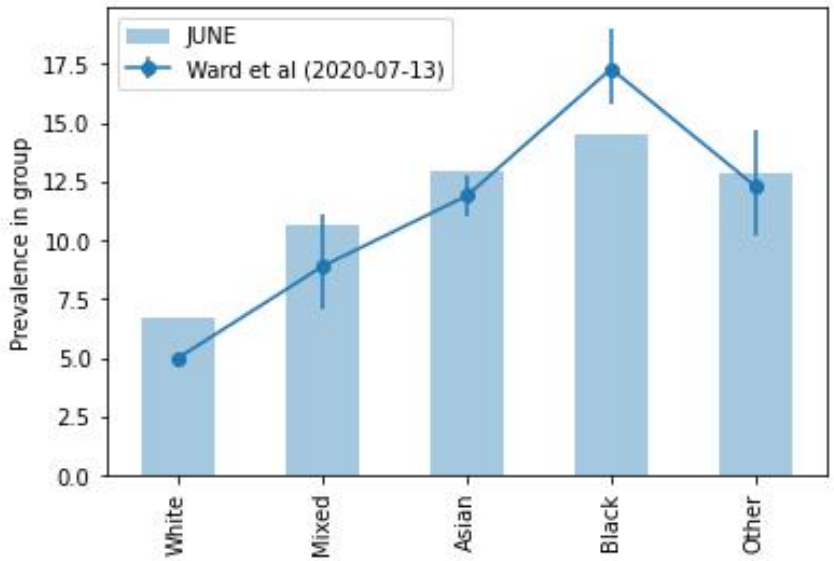
- look at cumulative infection rates until July 2020 in dependence on
  - age band
  - household size
  - ethnicity
- keep in mind: all imbalances only due to regional and sociological differences encoded in census data



impact of household size



impact of ethnicity

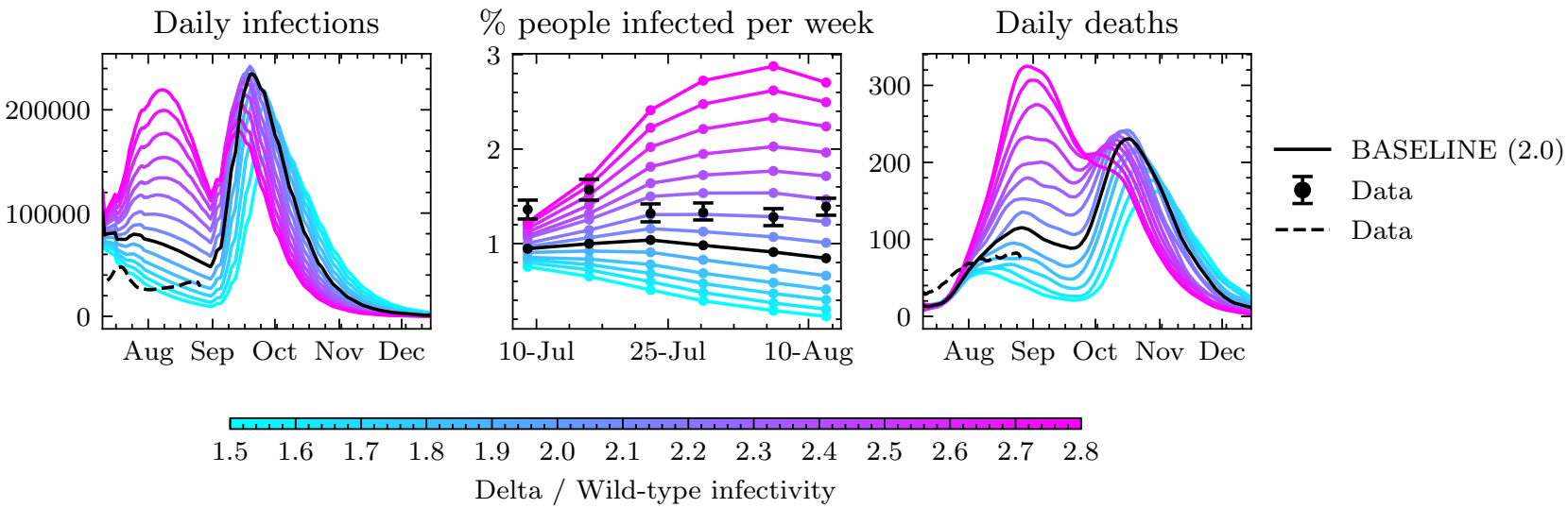


JUNE projections for ongoing waves

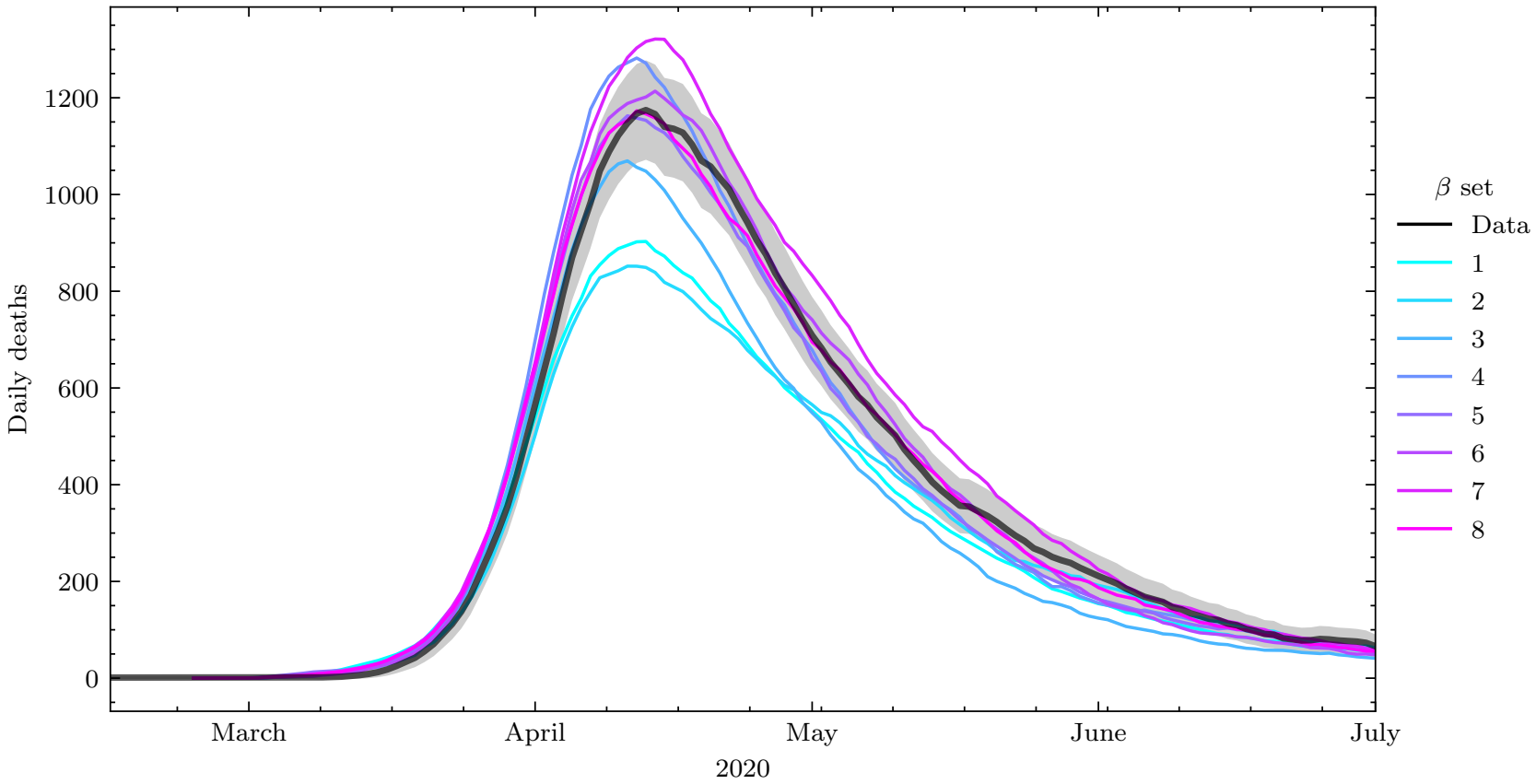
JUNE projections

- below a selection of JUNE projections for NHS England
- often in absence of good data:
  - school reopening in September 2022: Delta
  - Omicron projections at Christmas 2022
- additional issues:
  - fractured sociology: adherence to rules/own rules, vaccinations
  - individual daily routines massively impacted by COVID

Delta infectivity

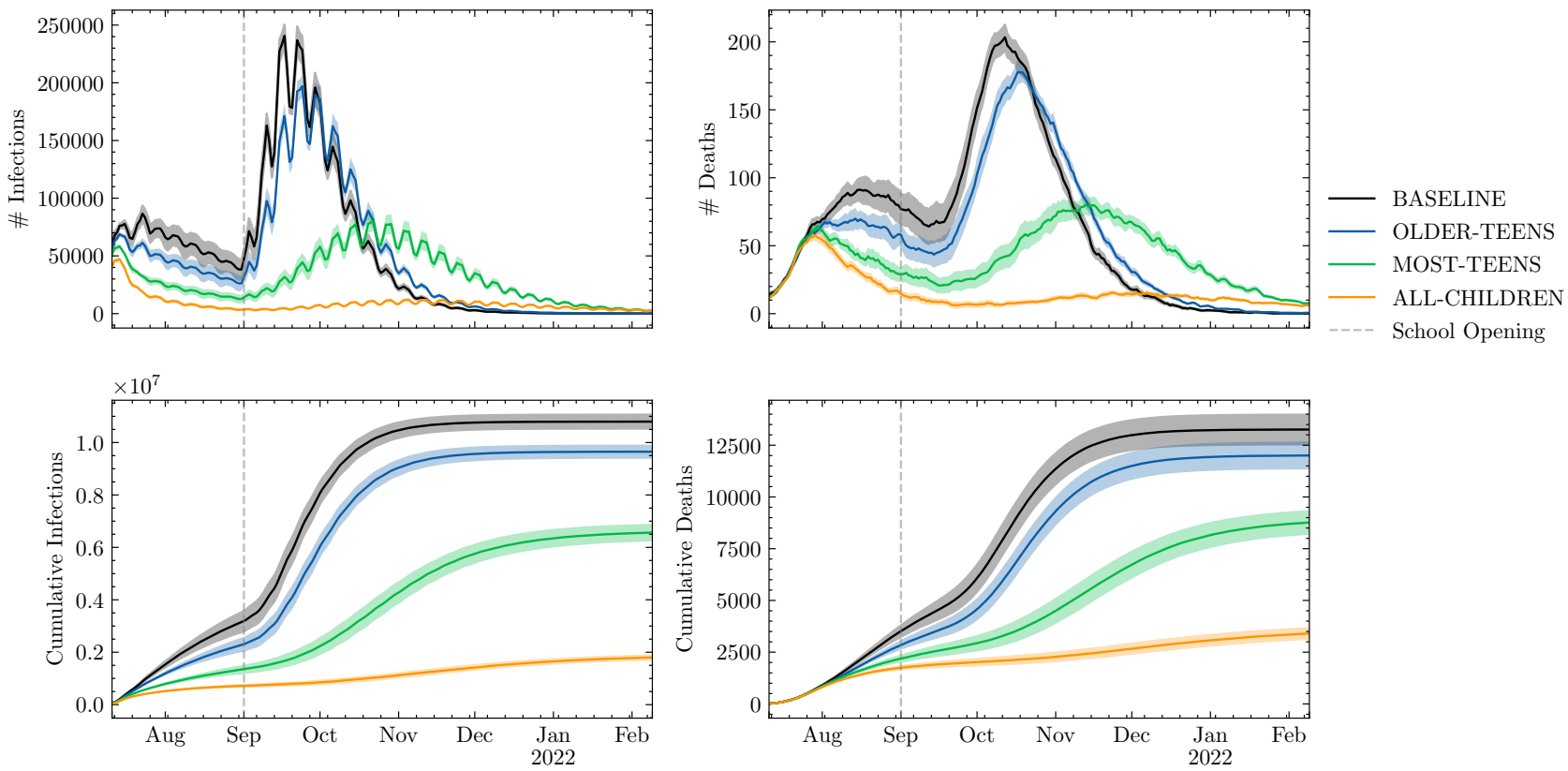


Daily deaths: projections vs data

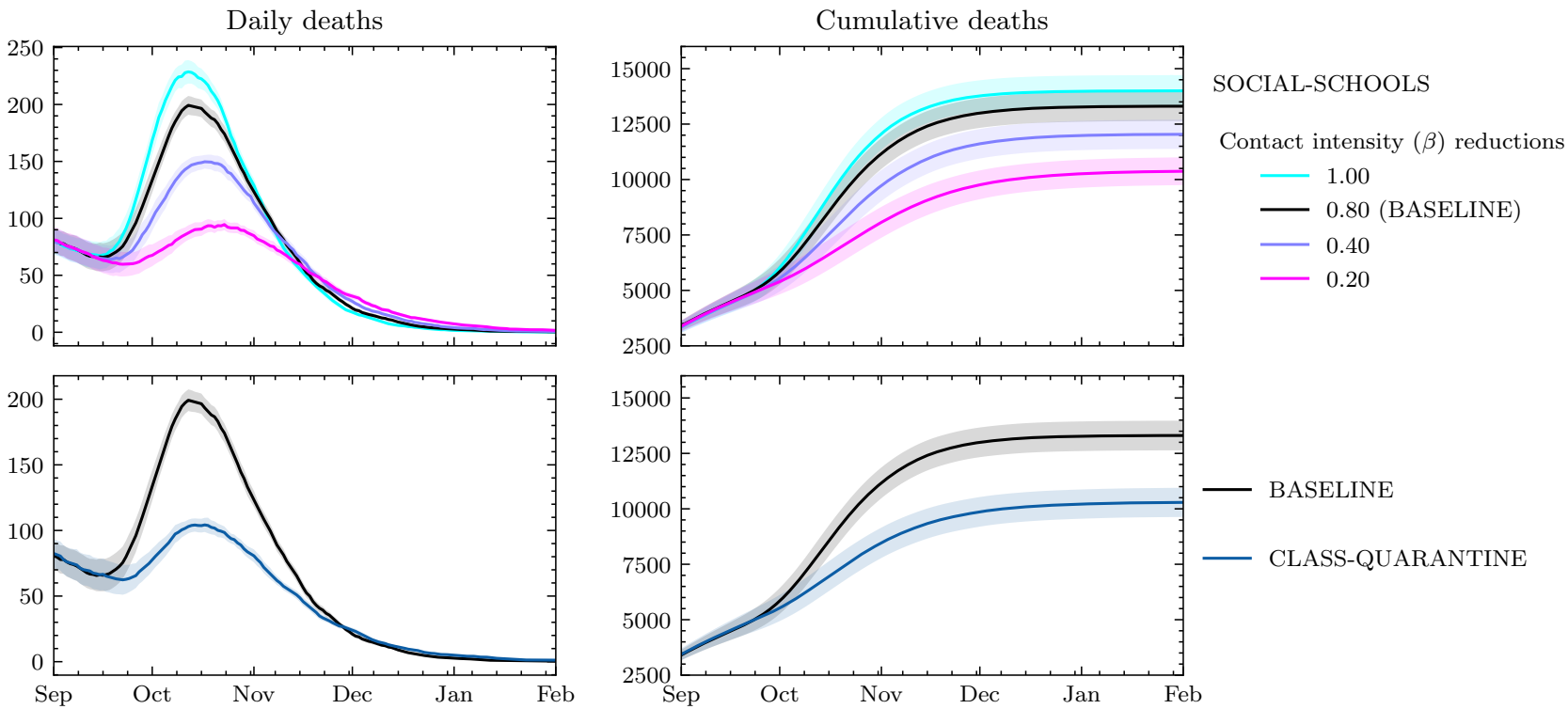


PIs in schools and their (projected) impact

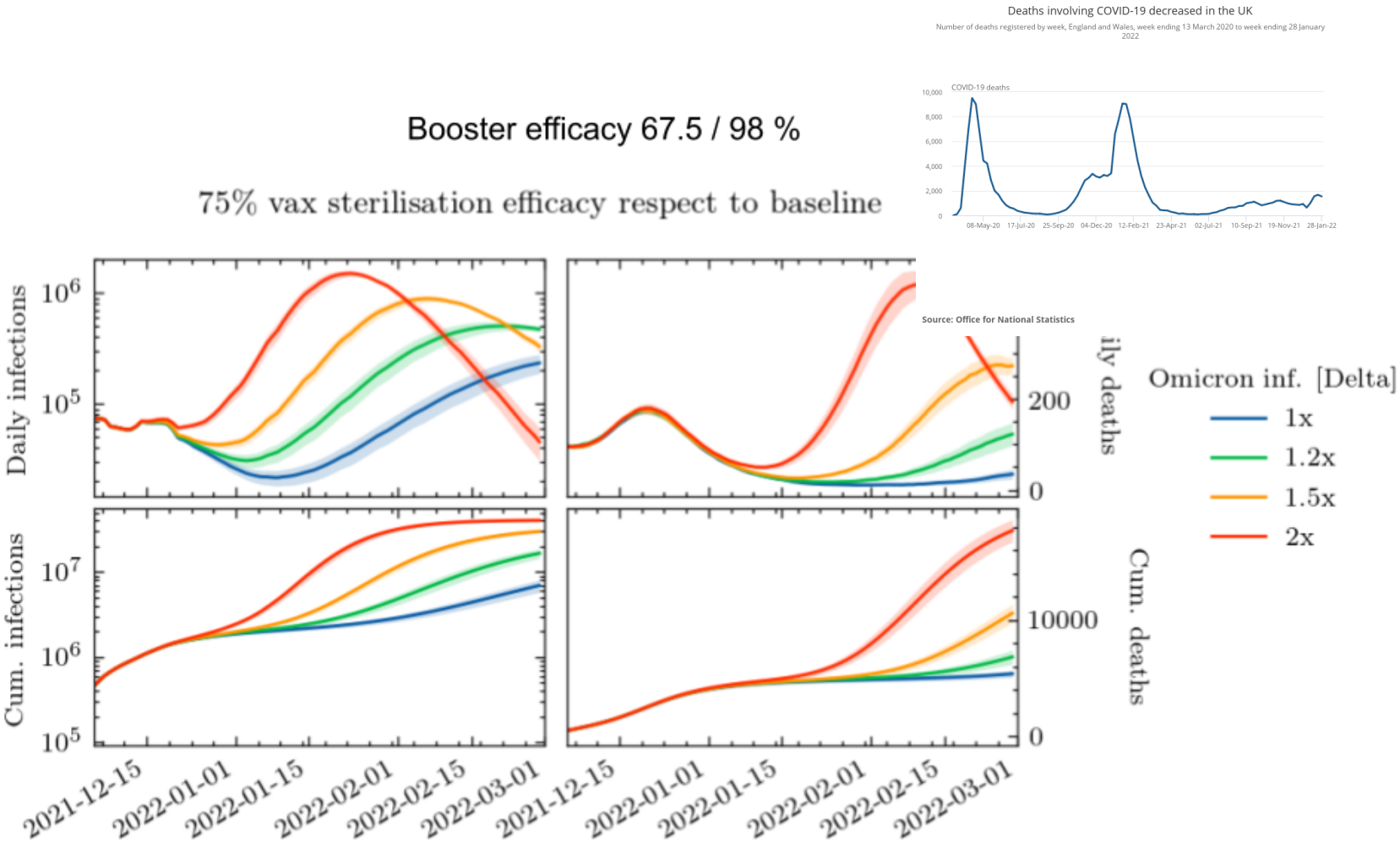
(different vaccination strategies by age: older > 16, most > 12 vs. baseline)



NPIs in schools and their (projected) impact



omicron projections



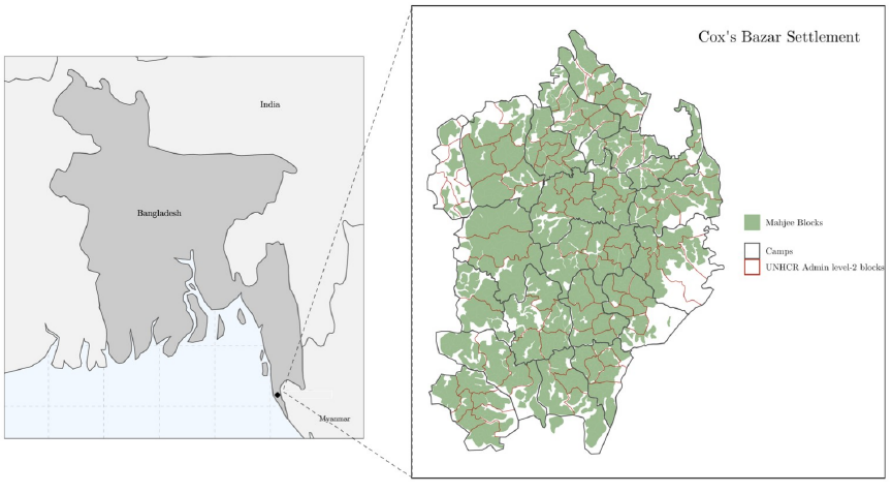
a spin-off:

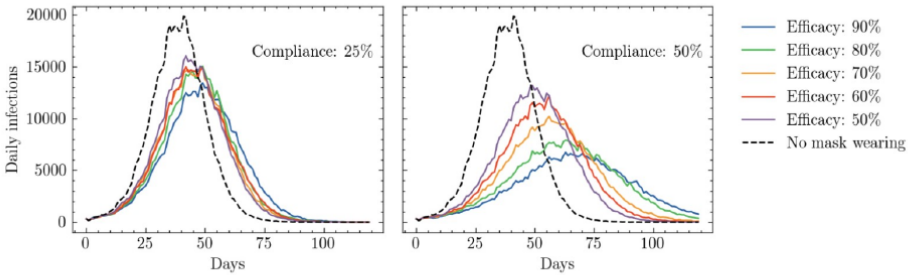
JUNE for Cox's Bazaar Refugee Operation

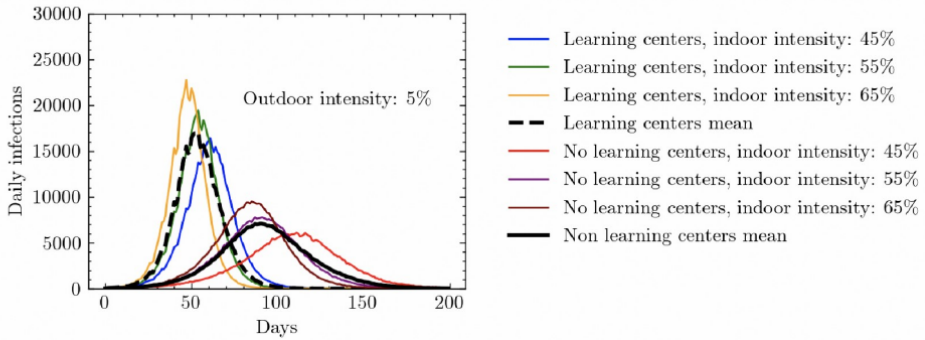
- one of our former PhD students (J.Bullock) has spent 6 months of placement with UN Global Pulse in New York
- ongoing contact, now working for UN-GP
- as a result, three students collaborated with WHO, UN-Global Pulse, and IBM-MIT Watson AI lab to provide tools for scenario planning for Cox's Bazaar in Bangladesh

(huge refugee camp, Rohingya crisis in Myanmar)

- largest settlement in the world
- in some areas, the settlement is denser than New York City
- high risk of COVID transmission




Compliance: 25%
Compliance: 50%
Daily infections
Days
Efficacy: 90%
Efficacy: 80%
Efficacy: 70%
Efficacy: 60%
Efficacy: 50%
No mask wearing


Outdoor intensity: 5%
Daily infections
Days
Learning centers, indoor intensity: 45%
Learning centers, indoor intensity: 55%
Learning centers, indoor intensity: 65%
Learning centers mean
No learning centers, indoor intensity: 45%
No learning centers, indoor intensity: 55%
No learning centers, indoor intensity: 65%
Non learning centers mean

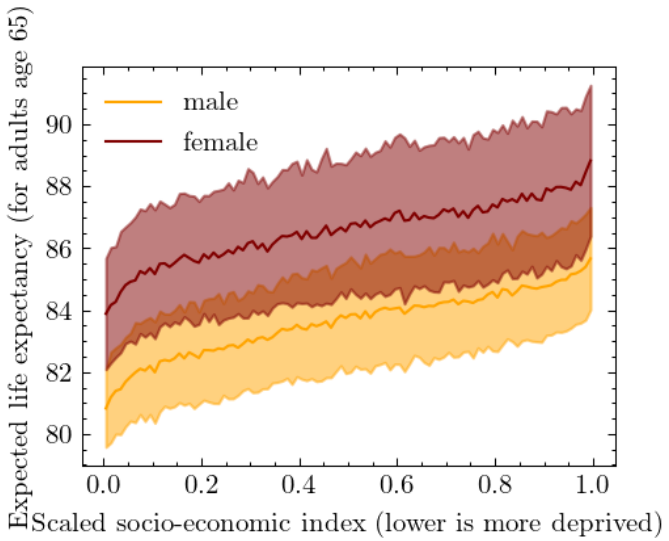
conclusions & outlook

summary

- epidemiology is an interesting field of science
- constructed an individual-based model with supreme granularity: demography, geography, sociology
- model informed operational planning of NHS:
  - → early warning of second wave
  - → projections for school re-opening
  - → projections for Delta and omicron waves
  - → understanding of transmission sociology
- code is highly flexible:
  - → addition of new effects & policies relatively painless
  - → adaptation to new environments: Cox's Bazaar
  - → adaptation to Germany underway (M.Schott, U Mainz)
- challenge to widespread perception in computational sociology: more and better detail often helps

outlook

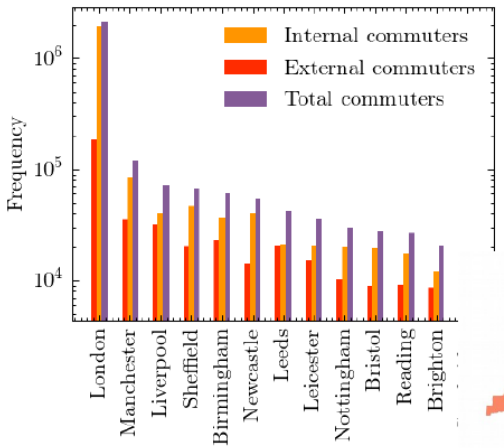
- vaccine waning: probabilistic effect?
- refine modelling for settlements: better understanding of sociology
- follow-up studies on social imbalances: ethnicity, IFR in dependence on socio-economic deprivation
- continue decision support for NHS:
  - impact of mutations: added variants
  - impact of vaccination protocols: take-up, efficacy
  - new fits underway (difficult sociology)

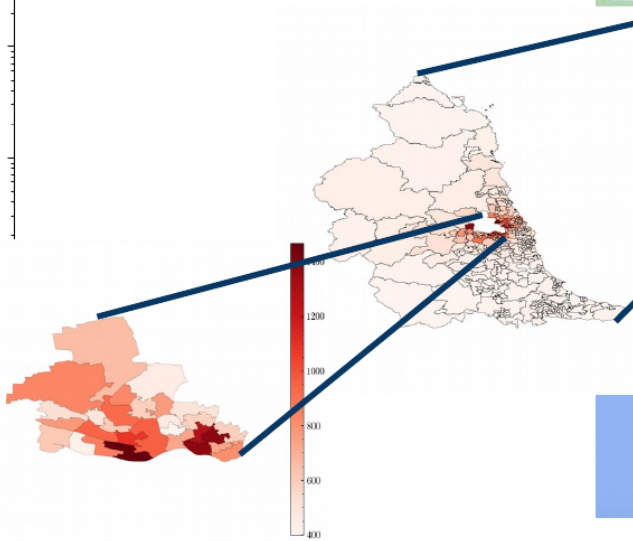


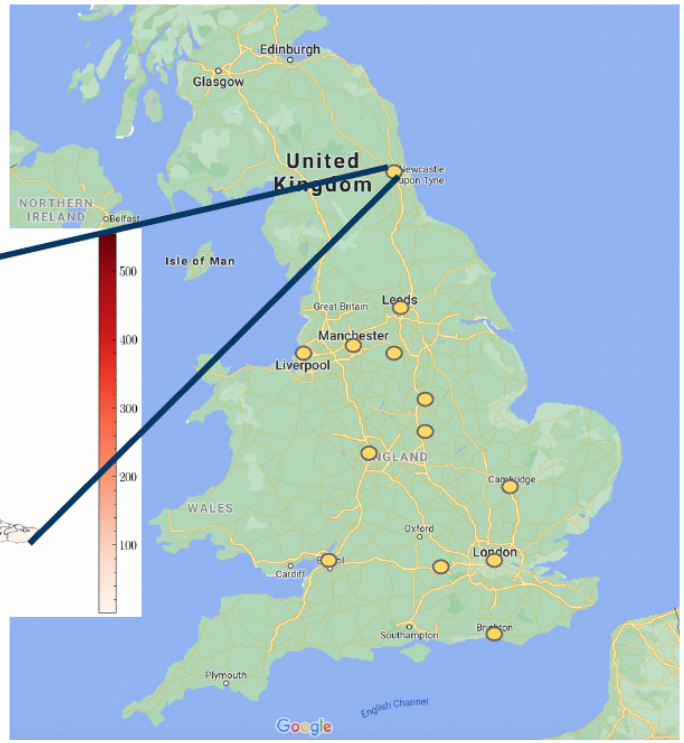
commuting patterns

- distinguish commuting into and within metropolitan areas

(external vs. internal commuters)







simulating daily structure

- JUNE allows flexible daily routines, separation of weekday/weekend
- time spent on activities known from ONS surveys

(this changes under lock-down)

- can translate into age-dependent probabilities for activities