Public Health England

Protecting and improving the nation's health

Informing the public health response to a disease outbreak caused by an aerosolised release of a biological agent

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Overview

Introduction

Calculating Uncertainty:

- Mathematical Modelling: Within-host and Atmospheric dispersion
- Statistical Inference: Maximum likelihood and Bayesian approaches

Communicating Uncertainty:

- Spatio-temporal Forecasts: Best-fit and Uncertainty
- Visual Aids: Graphs, Maps and Tables

Limitations and Future Developments

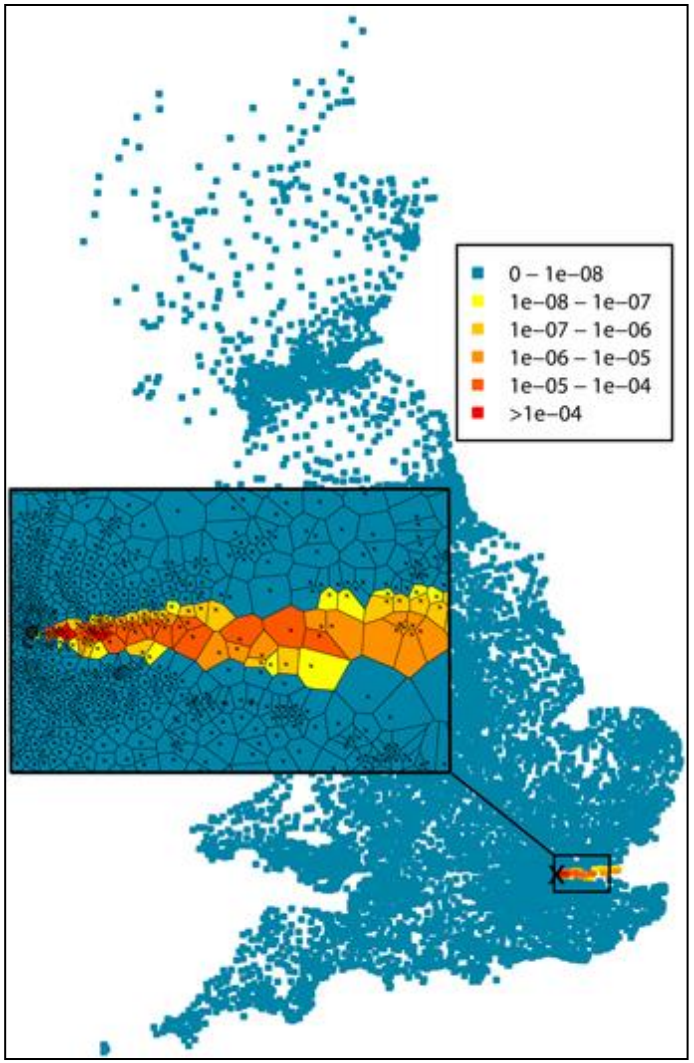
Introduction

Concern:

- Low probability, high impact
- Covert aerosolised release
- Highly pathogenic organism

Challenge:

- Based on early hospitalised persons
- Estimate when and where it occurred
- Estimate who else has been exposed
- Target medical counter-measures



Calculating Uncertainty (1)

Temporal component, t: **Within-host modelling**

Inhaled dose, d

Probability of infection, $p(d;\lambda,\theta)$

Incubation period distribution

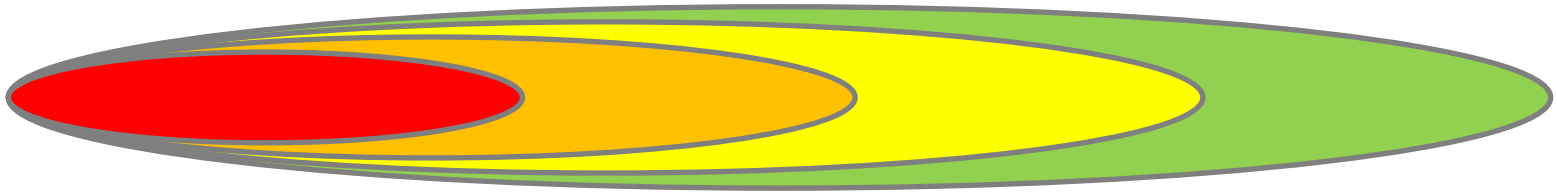
- Probability density function, $f(t,d;\lambda,\theta,r)$
- Cumulative distribution function, $F(t,d;\lambda,\theta,r)$

'Known' parameters:

- Clearance rate, θ
- Germination rate, λ
- Growth rate, r

Calculating Uncertainty (2)

Spatial component, $\{x, y, z\}$: **Atmospheric dispersion modelling**



Ground level inhaled dose, $d(x, y, z = 0; X, Y, S, u, Z, b, \sigma_x, \sigma_y, \sigma_z)$

Unknown parameters:

- Location of release, $\{X, Y\}$
- Number of spores released, S
- Wind speed in downwind direction, u

'Known' parameters:

- Height of release, Z
- Breathing rate, b
- Dispersion parameters, $\{\sigma_x, \sigma_y, \sigma_z\}$

Calculating Uncertainty (3)

Parameter inference: **Maximum likelihood estimation**

Likelihood, $L = \prod_{i=1}^{k} \frac{p(d_i) f(t_i - T, d_i)}{F(\tau - T, d_i)} \prod_{i=k+1}^{E} 1 - p(d_i) F(\tau - T, d_i)$

Where, $d_i = d(x_i, y_i; S, X, Y, \boldsymbol{\Omega})$

Unknown parameters:

- Time of release, T

'Known' parameters:

- 8 parameters plus, $\boldsymbol{\Omega}$

Data:

- Current (right-censoring) time, τ
- Number of symptomatic persons, k
- Home & work locations, $\{x_i, y_i\}$
- Times of symptom onset, t_i
- Exposed population, E

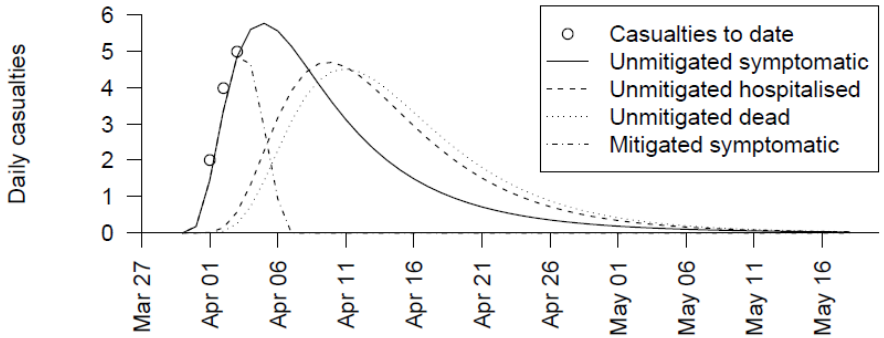
Calculating Uncertainty (4)

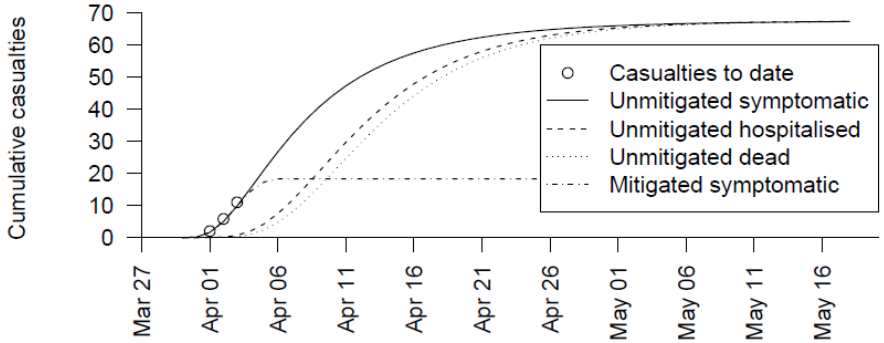
Prior knowledge: **Semi Bayesian framework**

Unknown parameter	Parameter description	Prior distribution	Default grid-search criteria
$\{X, Y\}$	Location	Uniform	5 km from home or work
T	Time	Uniform	1 week in the past
S	Strength	Log-Uniform	10^7 – 10^{20} spores
u_d	Wind direction	Met data	32 compass points
u_s	Wind speed	Met data	0 – 10 m/s

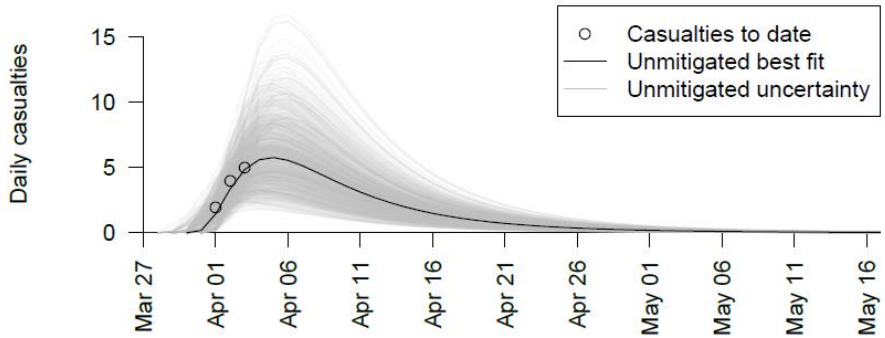
Communicating Uncertainty (1)

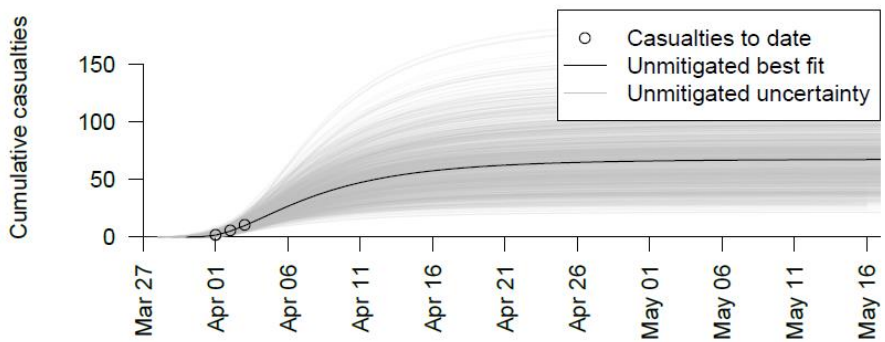
Best-fit





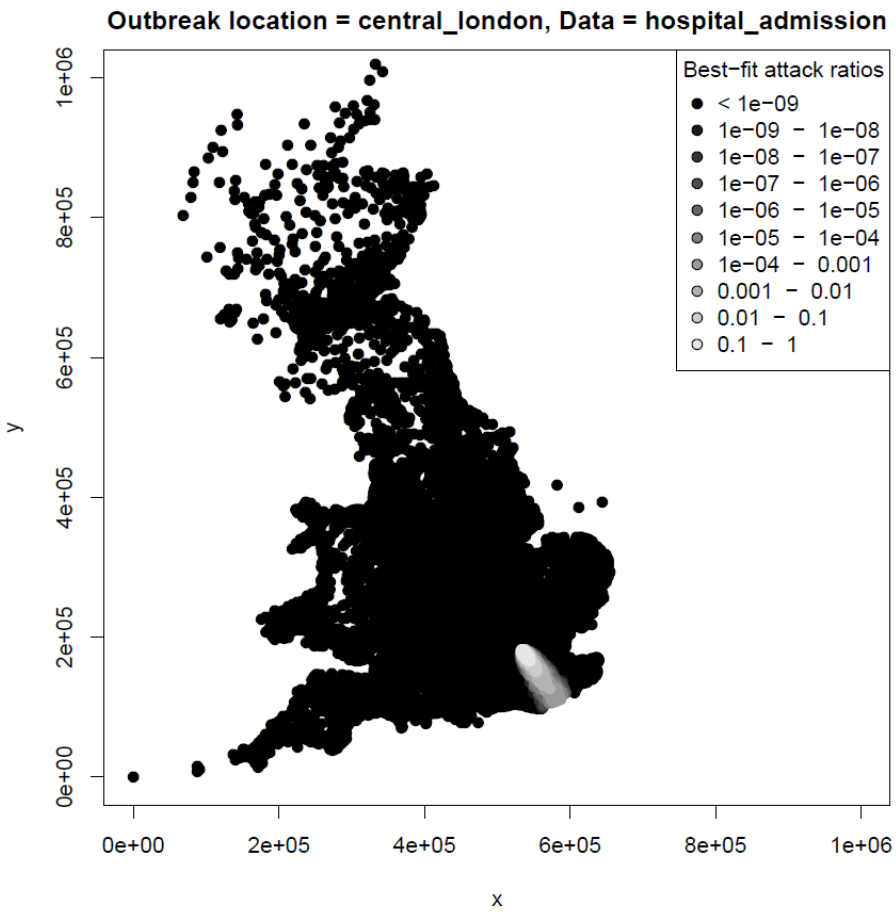
Uncertainty



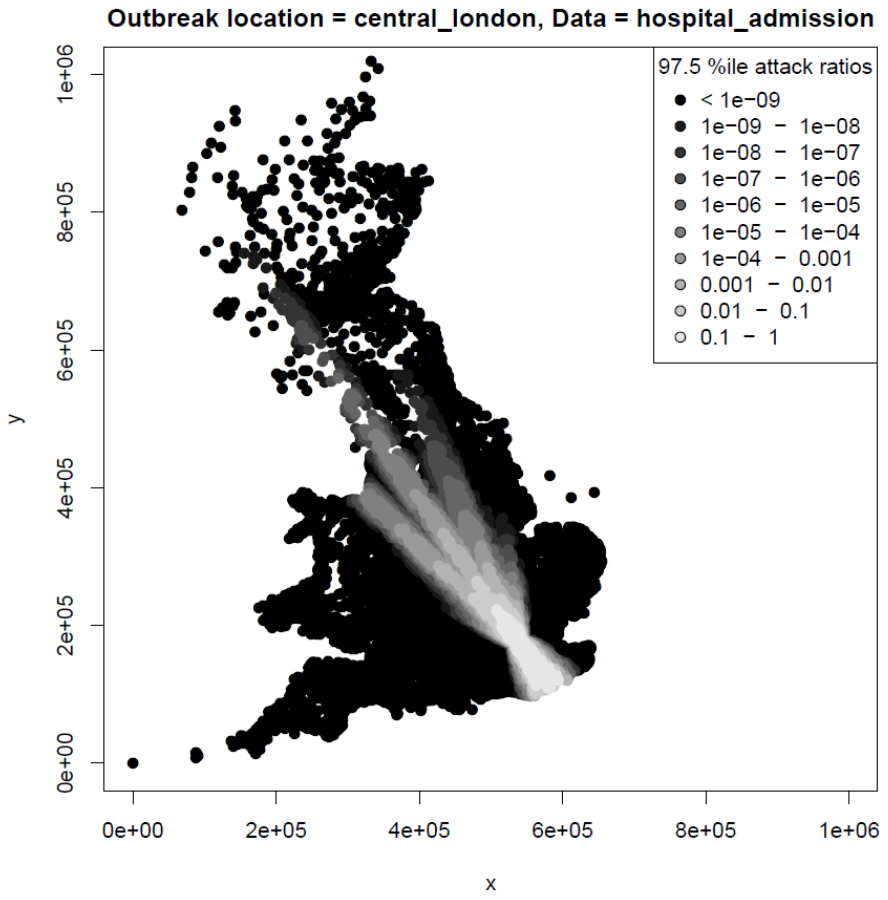


Communicating Uncertainty (2)

Best-fit

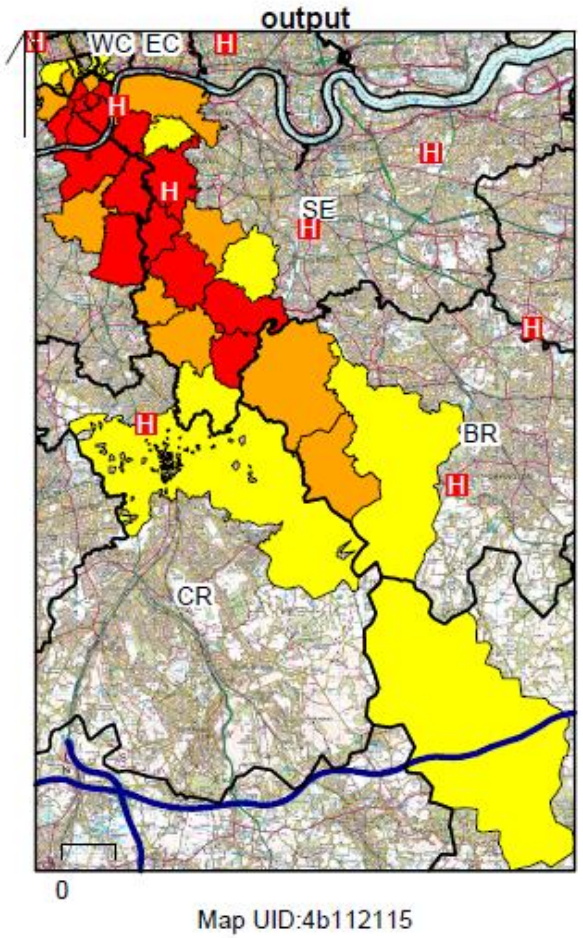


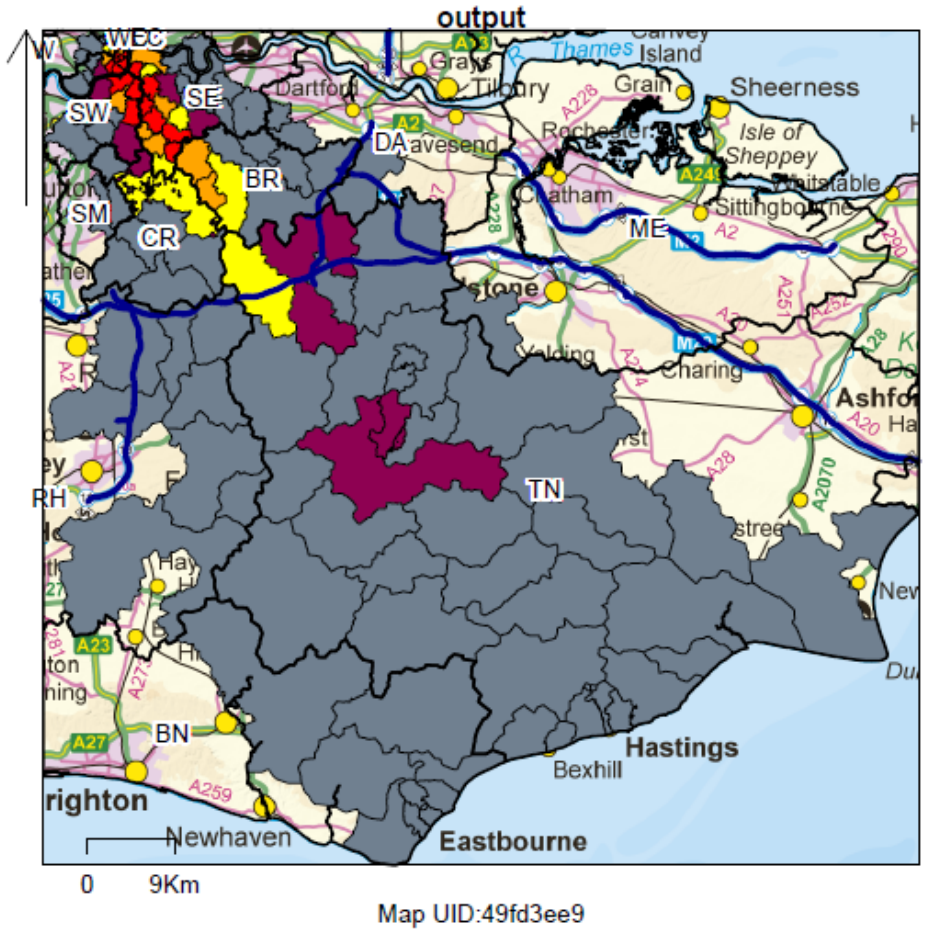
Uncertainty



Communicating Uncertainty (3)

Best-fit priority areas (2 different scales)





Communicating Uncertainty (4)

Best-fit summary table

Tranche	Population					Prisons	Nursing Homes	Care Homes	Hospices	ACCs in tranche	Schools	Start time of tranche (days)
1	401,792	95,153	85,638	33,498	37	1	38	72	0	1	84	6.0
2	417,746	12,047	10,843	4,605	41	0	30	60	1	1	66	6.8
3	401,773	2,395	2,156	932	40	0	24	62	0	0	90	7.4
4	405,011	252	227	112	40	0	82	164	0	1	105	8.7
5	386,335	69	62	33	39	0	69	131	1	1	88	9.6
6	410,348	4	3	2	41	0	150	283	2	1	103	10.5
7	401,890	0	0	0	40	1	95	181	0	2	149	11.4
8	378,933	0	0	0	38	1	90	184	2	1	140	12.3
9	488,929	0	0	0	49	0	92	149	2	0	124	13.2
10	169,530	0	0	0	17	0	46	102	1	1	52	14.0
Totals	3,862,288	109,920	98,928	39,182	382	3	716	1,388	9	9	1,001	-

Limitations & Future Developments

Data uncertainty:

Problem: Exposed at either home or work and not elsewhere

Partial solution: Need to incorporate travel history

Structural uncertainty:

Problem: Simple atmospheric dispersion model

Partial Solution: Need to test robustness

Parameter uncertainty:

Problem: Many input parameters are fixed

Partial Solution: Move to full Bayesian approach?

References

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A review of back-calculation techniques and their potential to inform mitigation strategies with application to non-transmissible acute infectious diseases, (submitted)

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