Considerations about case importations in the context of COVID-19

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* The University of Manitoba campuses are located on original lands of Anishinaabeg, Cree, Oji-Cree, Dakota and Dene peoples, and on the homeland of the Métis Nation.
We respect the Treaties that were made on these territories, we acknowledge the harms and mistakes of the past, and we dedicate ourselves to move forward in partnership with Indigenous communities in a spirit of reconciliation and collaboration.

Pathogens have been mobile for a while

It first began, it is said, in the parts of **Ethiopia** above Egypt, and thence descended into **Egypt** and **Libya** and into most of the King's country [**Persia**]. Suddenly falling upon Athens, it first attacked the population in **Piraeus** [..] and afterwards appeared in the **upper city**, when the deaths became much more frequent.

Thucydides (c. 460 BCE - c. 395 BCE)

History of the Peloponnesian War

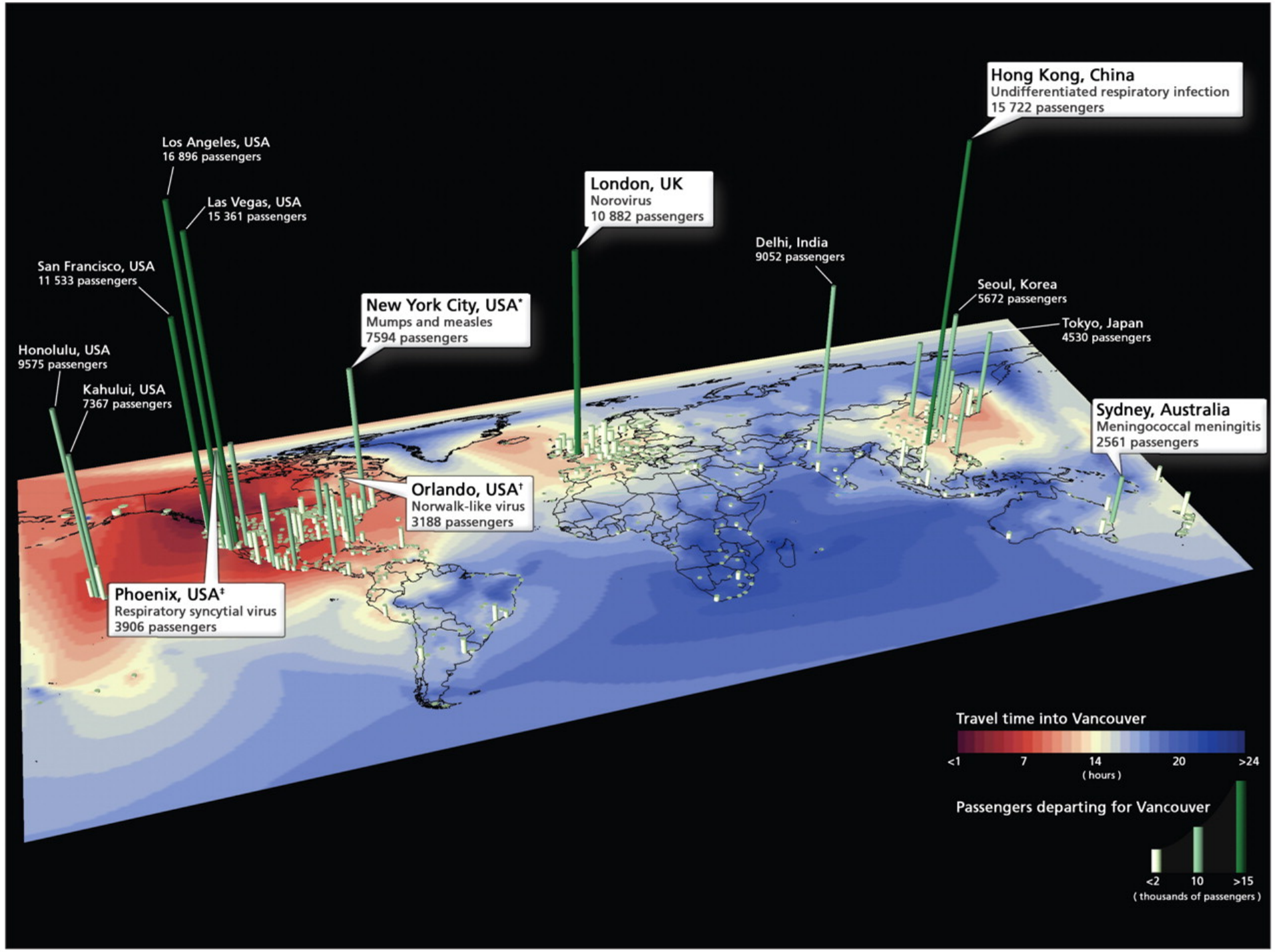
Outline

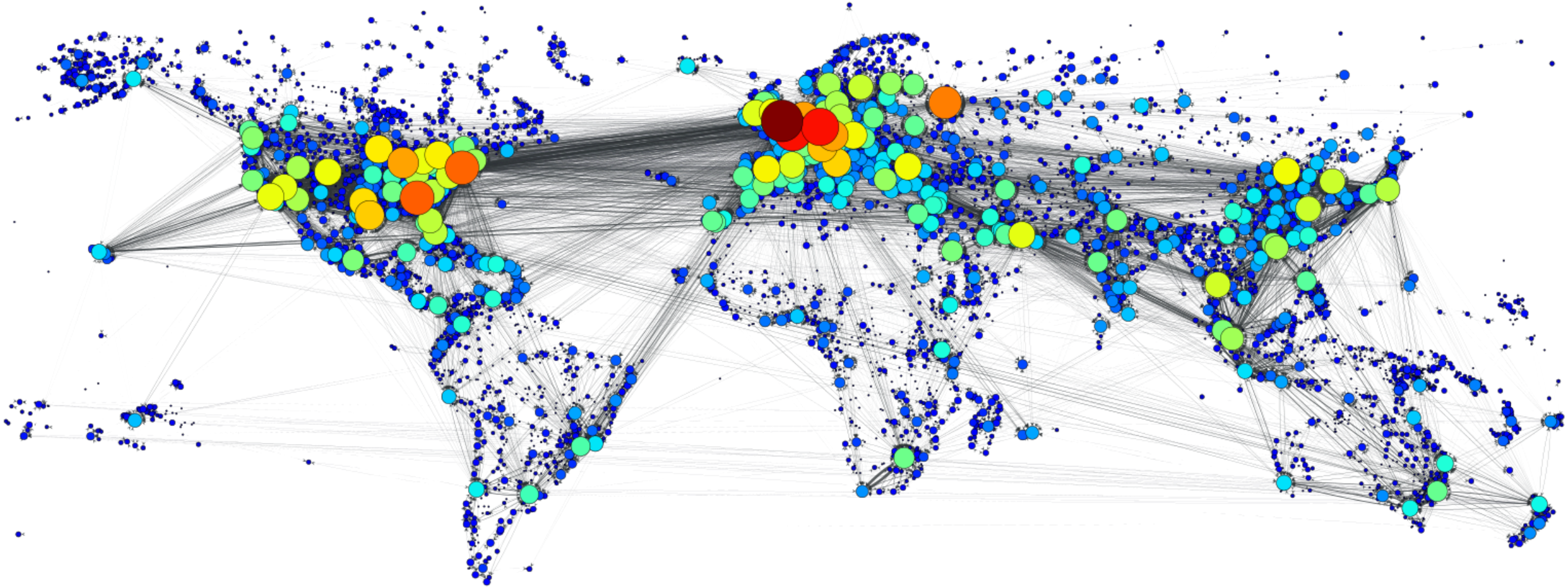
- Human habitat fragmentation, mobility and the spread of infectious diseases
- The first wave of COVID-19
- Case importations
- Spread of SARS-CoV-2 variants
- Role of transport restrictions
- Role of quarantine
- Lessons learned and key knowledge gaps

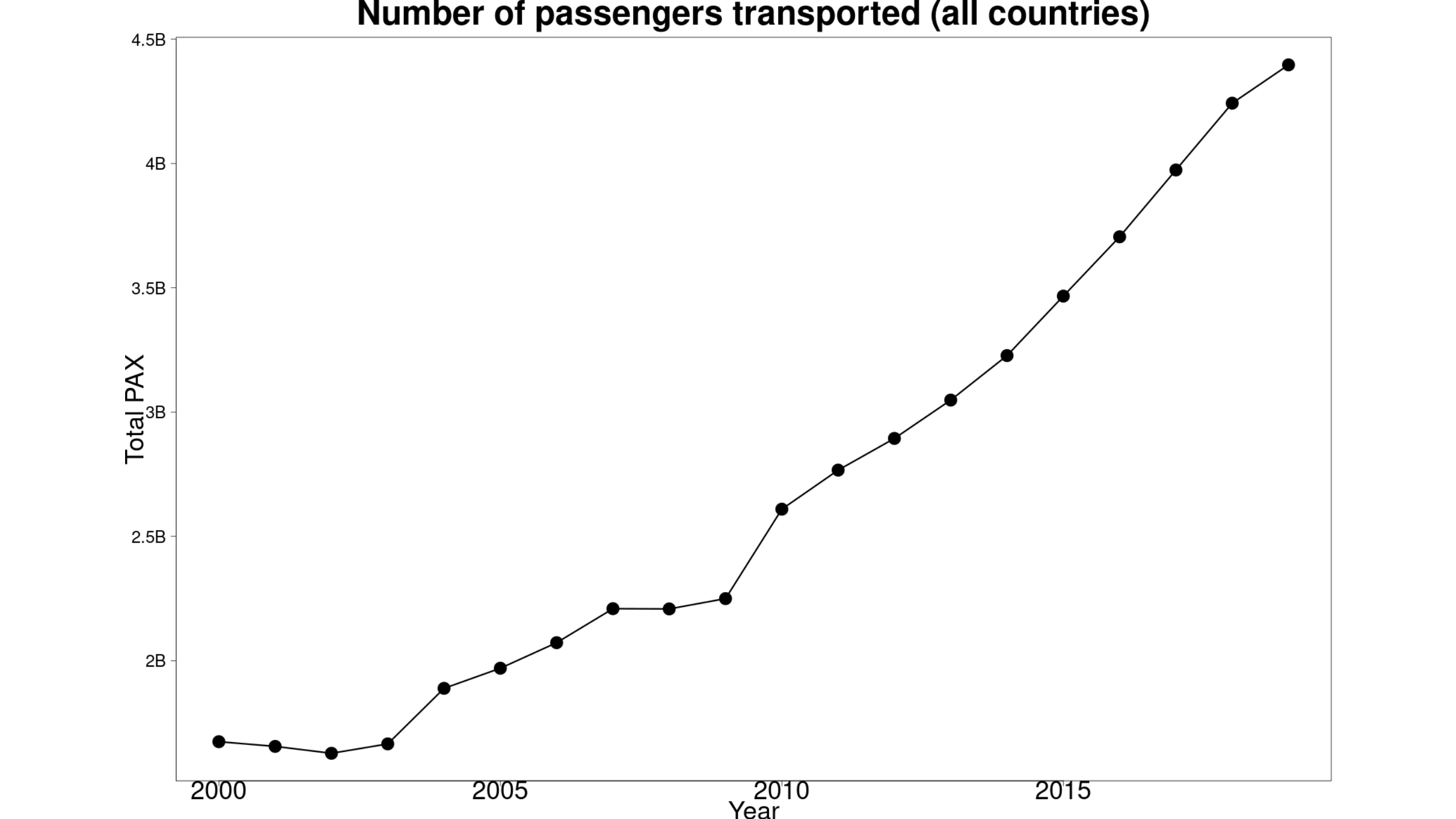
Human habitat fragmentation, mobility and the spread of infectious diseases

The human world is fragmented not only because of geography

- Political divisions (jurisdictions): nation groups (e.g., EU), nations, provinces/states, regions, counties, cities..
- Travel between jurisdictions can be complicated or impossible
- Data is integrated at the jurisdicional level
- Policy is decided at the jurisdictional level
- Long range mobility is a bottom$\rightarrow$top$\rightarrow$top$\rightarrow$bottom process


Hong Kong, China
Undifferentiated respiratory infection
15 722 passengers
Los Angeles, USA
16 896 passengers
Las Vegas, USA
15 361 passengers
London, UK
Norovirus
10 882 passengers
Delhi, India
9052 passengers
San Francisco, USA
11 533 passengers
New York City, USA*
Mumps and measles
7594 passengers
Seoul, Korea
5672 passengers
Tokyo, Japan
4530 passengers
Honolulu, USA
9575 passengers
Kahului, USA
7367 passengers
Sydney, Australia
Meningococcal meningitis
2561 passengers
Orlando, USA†
Norwalk-like virus
3188 passengers
Phoenix, USA‡
Respiratory syncytial virus
3906 passengers
Travel time into Vancouver
<1
7
14
20
>24
(hours)
Passengers departing for Vancouver
<2
10
>15
(thousands of passengers)




Number of passengers transported (all countries)
4.5B
4B
3.5B
3B
2.5B
2B
Total PAX
2000
2005
2010
2015
Year

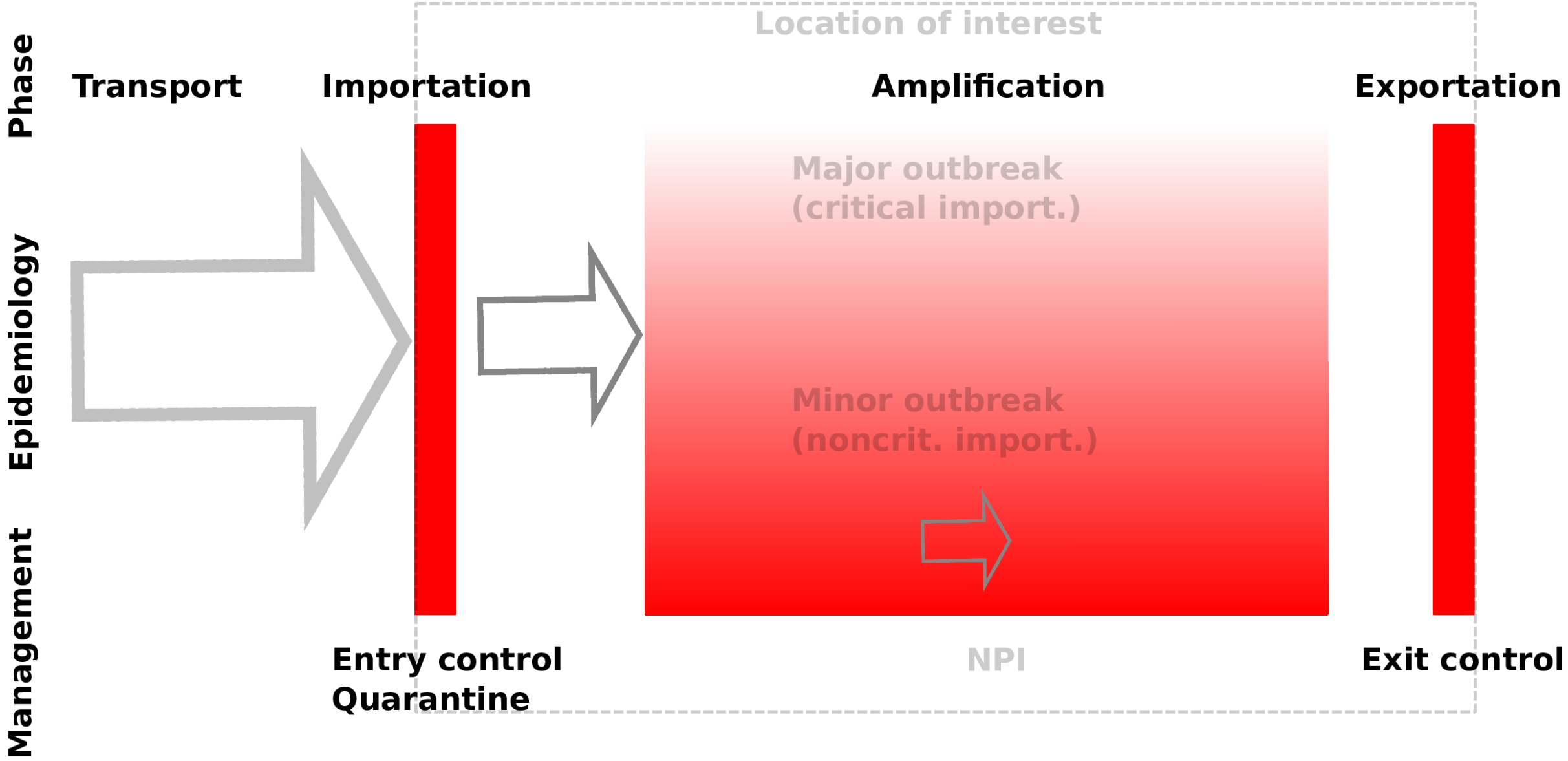
Mobility is complicated but determinant in disease spatialisation

- Multiple modalities: foot, bicycle, personal vehicle, bus, train, boat, airplane
- Various durations: trip to the corner shop $\neq$ commuting $\neq$ multi-day trip for work or leisure $\neq$ relocation, immigration or refuge seeking
- Volumes are hard to fathom

And yet **mobility drives spatio-temporal spread**:

- Black Death 1347-1353 arrived in Europe and spread following trade routes
- SARS-CoV-2 spread out of HKG following the GATN
- Khan, Arino, Hu *et al*, Spread of a novel influenza A (H1N1) virus via global airline transportation, *New England Journal of Medicine* (2009)

The spread process in a jurisdiction-based world



The first wave of COVID-19

J. Arino. Describing, modelling and forecasting the spatial and temporal spread of COVID-19 - A short review. To appear in Fields Institute Communications.

Amplification in Wuhan (Hubei province)

- Details of emergence and precise timeline before amplification started unknown
- Amplification in Wuhan
  - Cluster of pneumonia cases mostly related to the Huanan Seafood Market
  - 27 December 2019: first report to local government
  - 31 December 2019: publication
  - 8 January 2020: identification of SARS-CoV-2 as causative agent
- $\sim$ 23 January 2020: lockdown Wuhan and Hubei province + face mask mandates

By 29 January, virus was found in all provinces of mainland China

First detections outside China

Date	Location	Note
13 Jan.	Thailand	Arrived 8 Jan.
16 Jan.	Japan	Arrived 6 Jan.
20 Jan.	Republic of Korea	Airport detected on 19 Jan.
20 Jan.	USA	Arrived Jan. 15
23 Jan.	Nepal	Arrived 13 Jan.
23 Jan.	Singapore	Arrived 20 Jan.
24 Jan.	France	Arrived 22 Jan.
24 Jan.	Vietnam	Arrived 13 Jan.
25 Jan.	Australia	Arrived 19 Jan.
25 Jan.	Malaysia	Arrived 24 Jan.

Caveat : evidence of earlier spread

- Report to Wuhan authorities on 27 December 2019
- First export detections in Thailand and Japan on 13 and 16 January 2020 (with actual importations on 8 and 6 January)

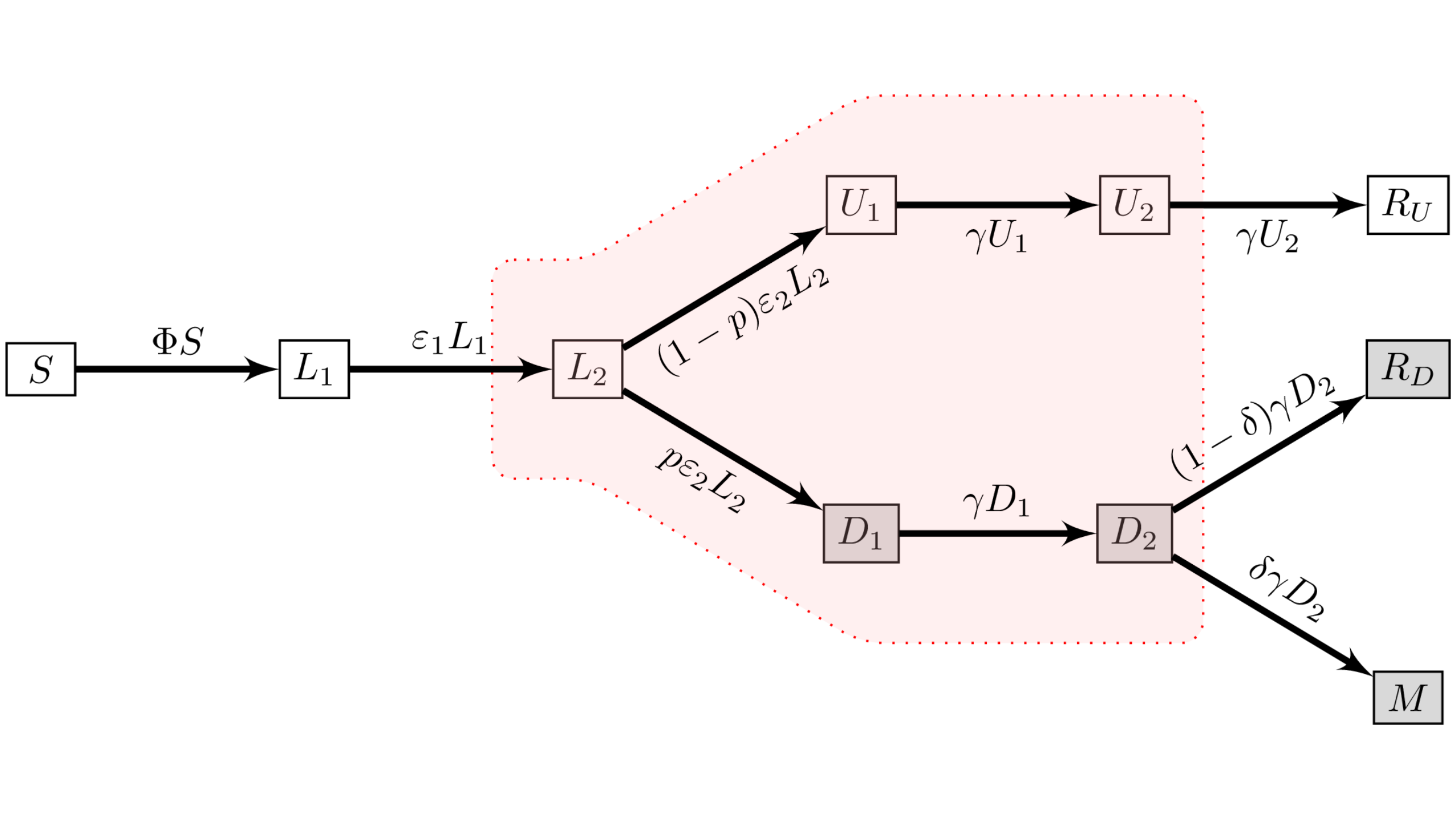
$\Longrightarrow$ amplification must have been occuring for a while longer

- France: sample taken from 42-year-old male (last foreign travel to Algeria in August 2019) who presented to ICU on 27 December 2019
- Retrospective studies in United Kingdom and Italy also showed undetected COVID-19 cases in prepandemic period

Untangling the first case issue

- Robert, Rossman & Jaric. Dating first cases of COVID-19. *PLoS Pathogens* (2021). Find likely timing of first case of COVID-19 in China as November 17 (95% CI October 4)
- Pekar, Worobey, Moshiri, Scheffler & Wertheim. Timing the SARS-CoV-2 index case in Hubei province. *Science* (2021). Period between mid-October and mid-November 2019 is plausible interval when the first case of SARS-CoV-2 emerged in Hubei province.

Important when trying to understand global spread, so let me illustrate with the model I used (J. Arino & S. Portet. A simple model for COVID-19. *Infectious Disease Modelling* 2020) [taking into account model evolution since]


S
ΦS
L_1
$\varepsilon_1 L_1$
L_2
$(1-p)\varepsilon_2 L_2$
U_1
γU_1
U_2
γU_2
R_U
$p\varepsilon_2 L_2$
D_1
γD_1
D_2
$(1-\delta)\gamma D_2$
R_D
$\delta\gamma D_2$
M

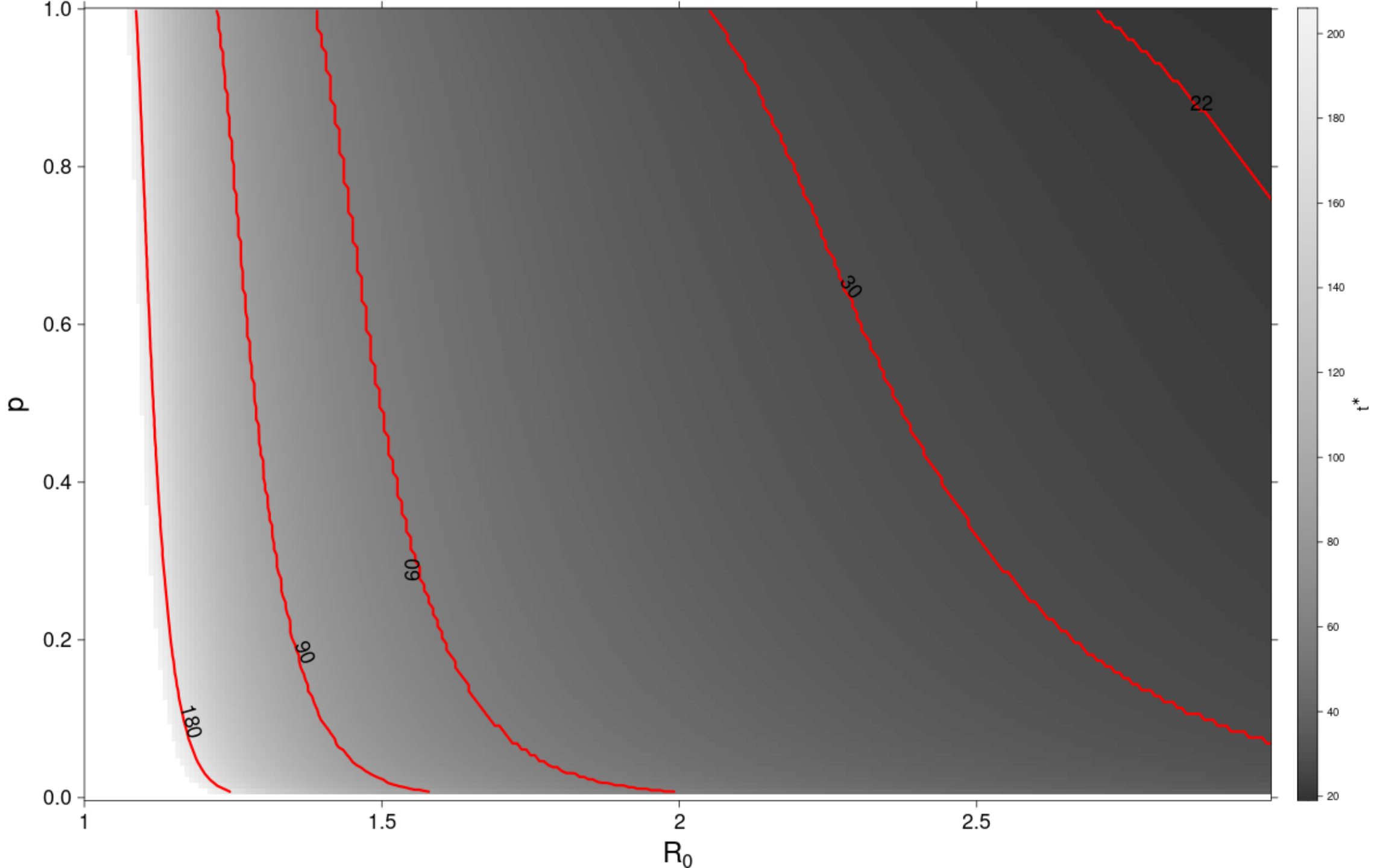
Back-calculating the start of spread (example of China)

Cumulative confirmed case counts in China as reported to WHO was $c = 547$ cases on $t_c = 2020\text{-}01\text{-}22$

Let u be a point in parameter space. Solve ODE numerically over $[0, t]$, with $S(0)$ the population of China, $L_1(0) = 1$ and other state variables 0. This gives a solution $x(t, t_0 = 0, u)$. Extracting $L_2(t, t_0 = 0, u)$ from this solution, obtain cumulative number of new detections as

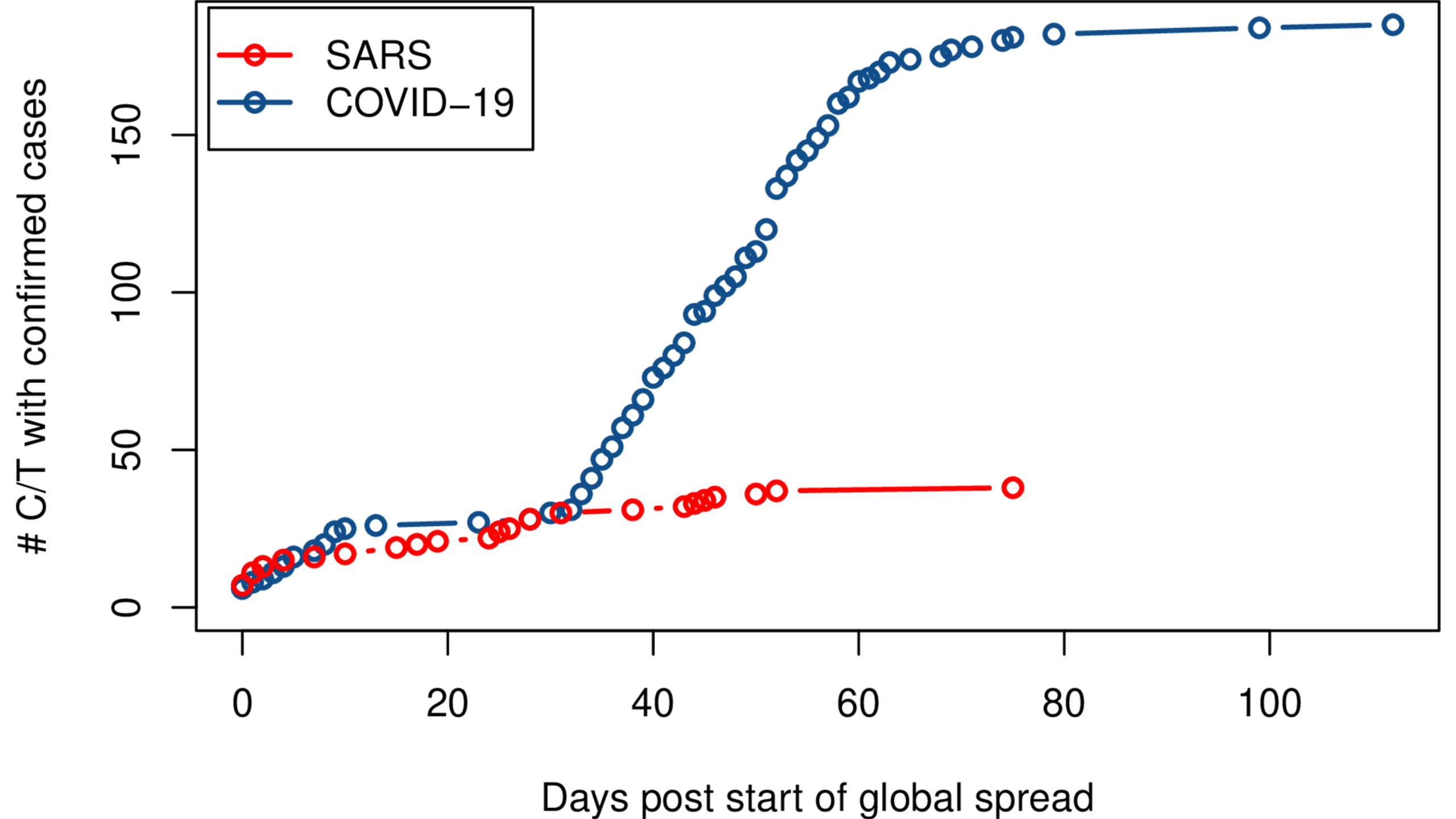
$$C(t) = \int_{t_0=0}^{t} p\varepsilon L_2(s, t_0, u)\, ds$$

Let t^* be s.t. $C(t^*) = 547$; then $t_i = 2020\text{-}01\text{-}22 - t^*$


p
R_0
t*
1.0
0.8
0.6
0.4
0.2
0.0
1
1.5
2
2.5
200
180
160
140
120
100
80
60
40
20
180
90
60
30
22

- For SARS-CoV-1 (2003), the point of introduction on the GATN is known with certainty (Metropole Hotel, HKG, 2003-02-21)
- For SARS-CoV-2, uncertainty remains and will probably never be lifted

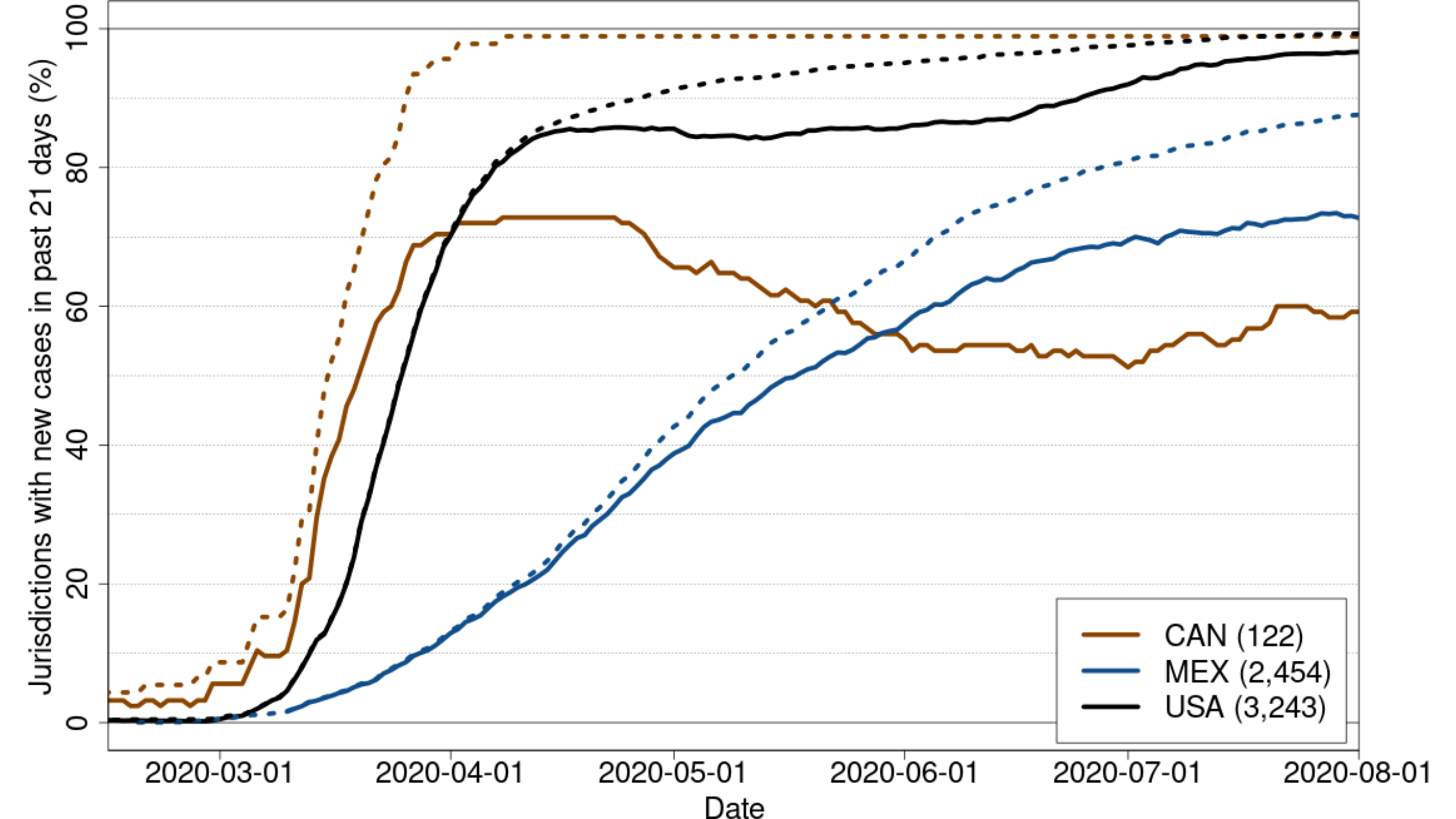
Back to the spatio-temporal spread of the **detected** first wave..

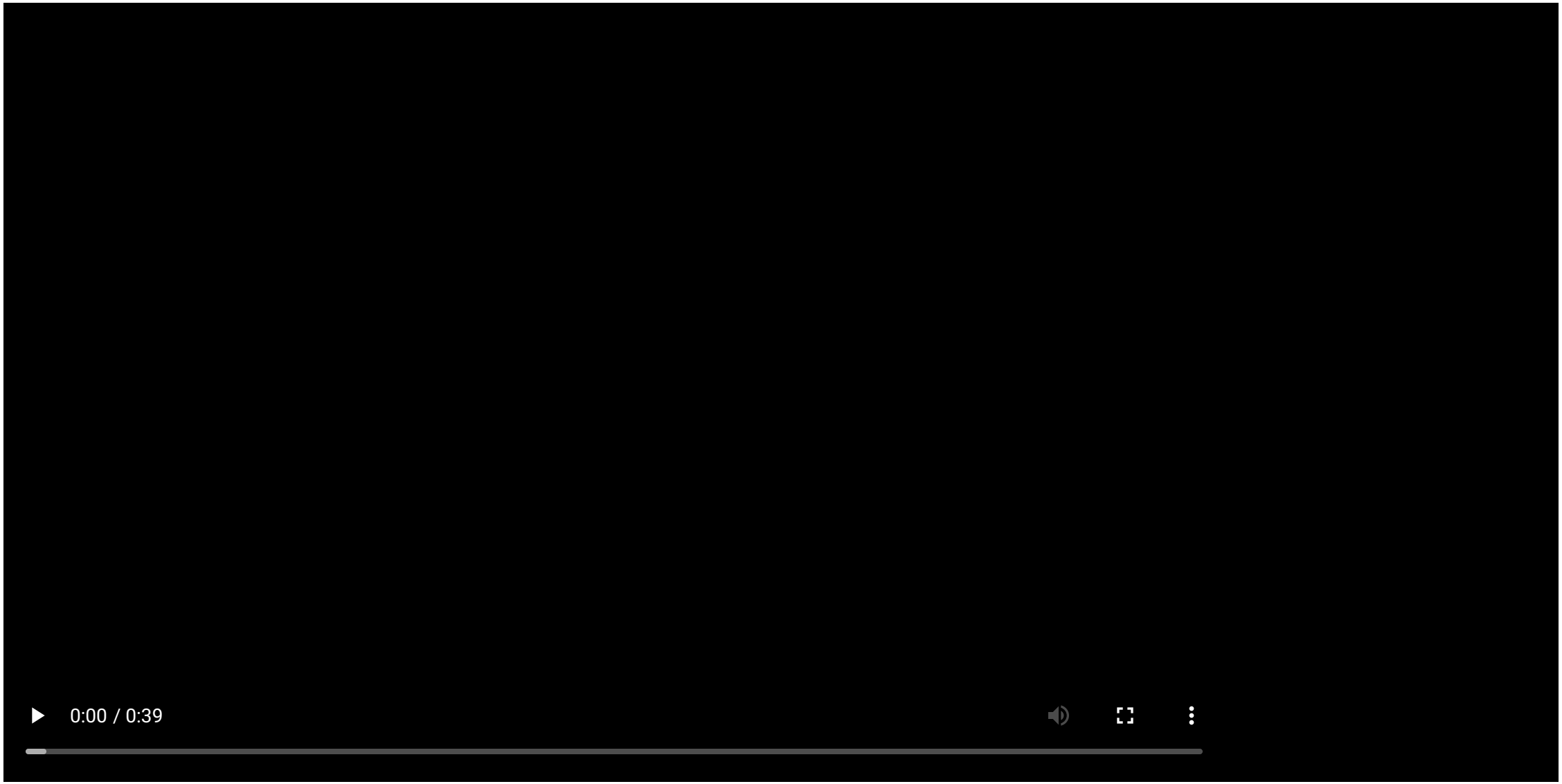

SARS
COVID−19
C/T with confirmed cases
0
50
100
150
0
20
40
60
80
100
Days post start of global spread

Transmission within national jurisdictions was heterogeneous

Moving from ISO-3166-3 (nation or territory) level to smaller sub-national jurisdictions, the picture is more contrasted

Next slide: Example of activation of North American health regions/municipios/counties


Jurisdictions with new cases in past 21 days (%)
0
20
40
60
80
100
2020-03-01
2020-04-01
2020-05-01
2020-06-01
2020-07-01
2020-08-01
Date
CAN (122)
MEX (2,454)
USA (3,243)


0:00 / 0:39

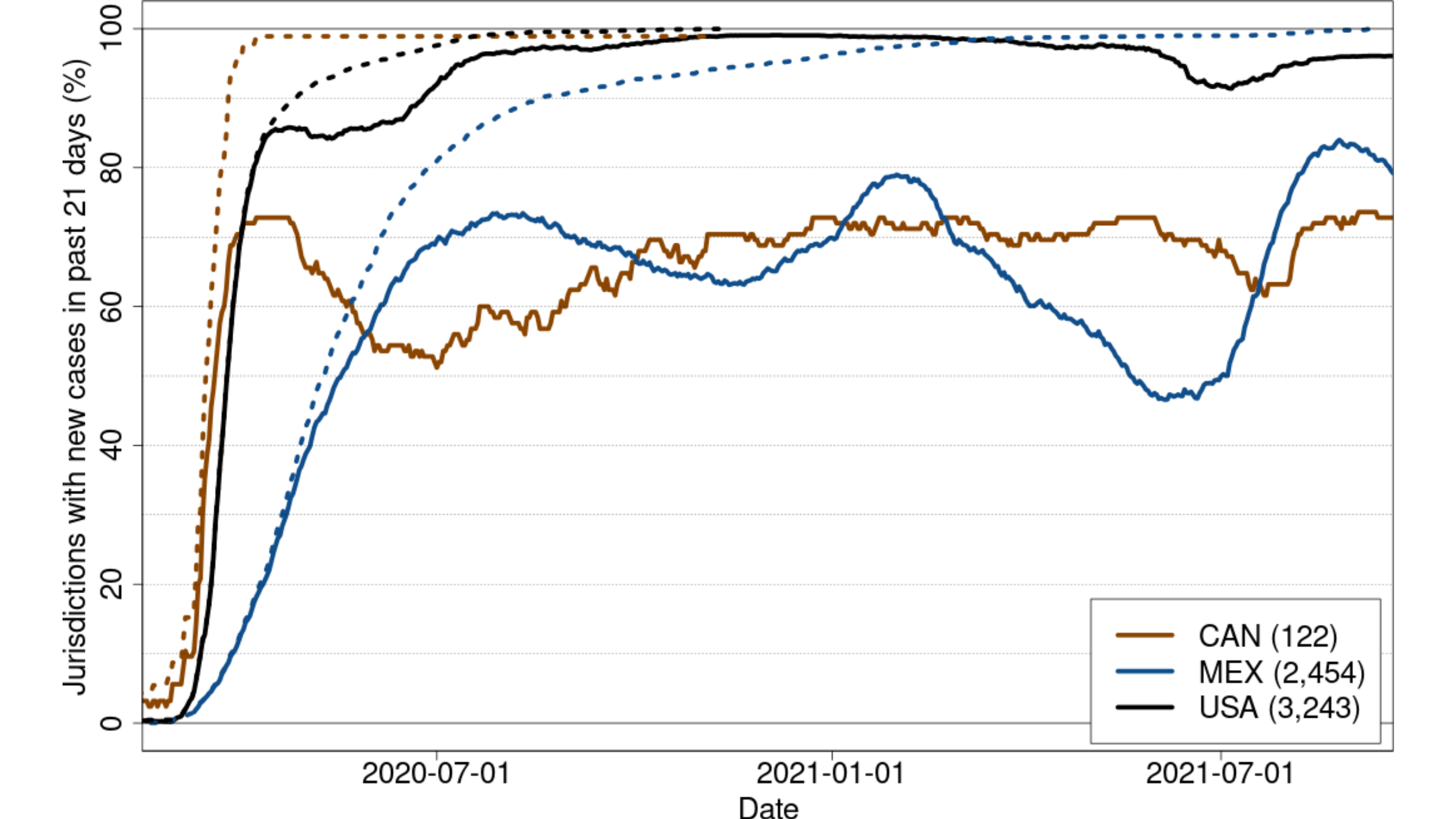
Case importations

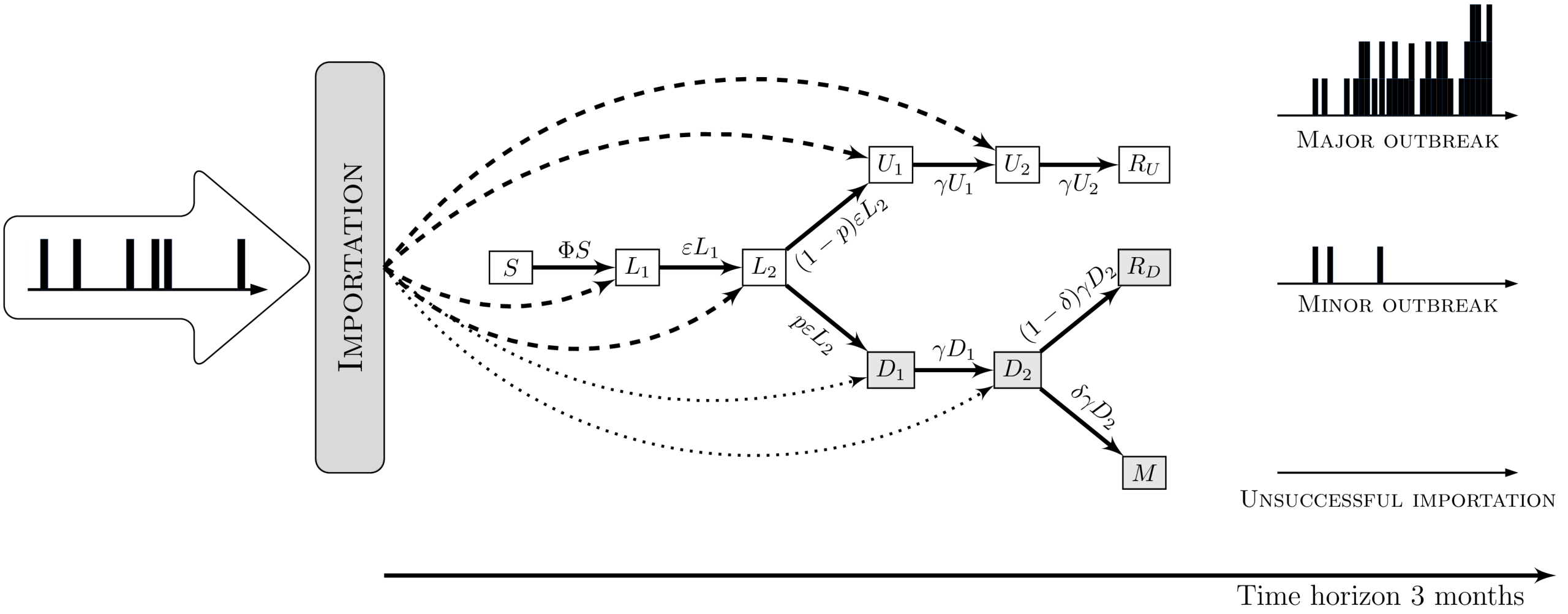
J. Arino & S. Portet. A simple model for COVID-19. Infectious Disease Modelling, 2020

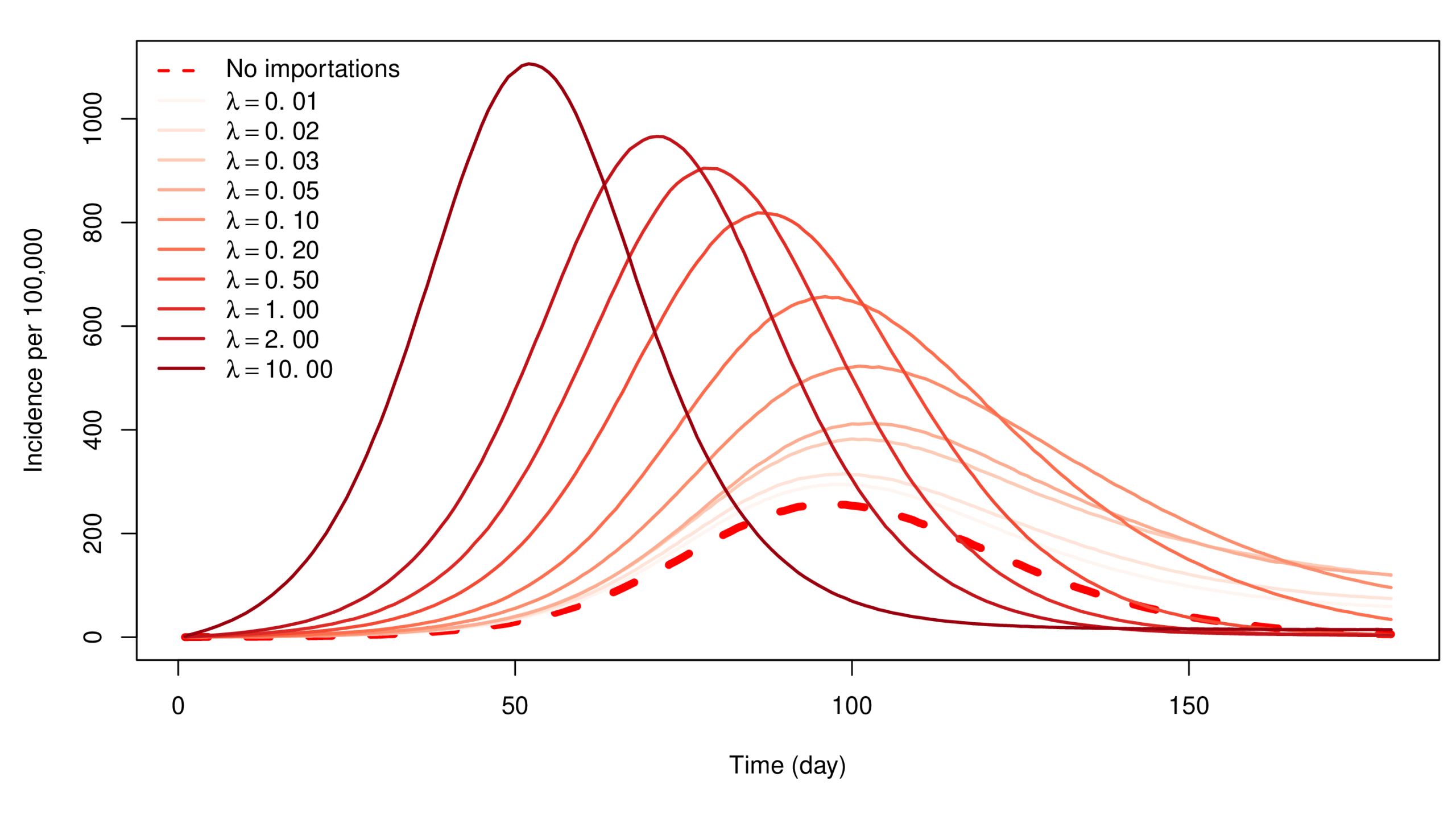
J. Arino, N. Bajeux, S. Portet & J. Watmough. Quarantine and the risk of COVID-19 importation. Epidemiology & Infection, 2020

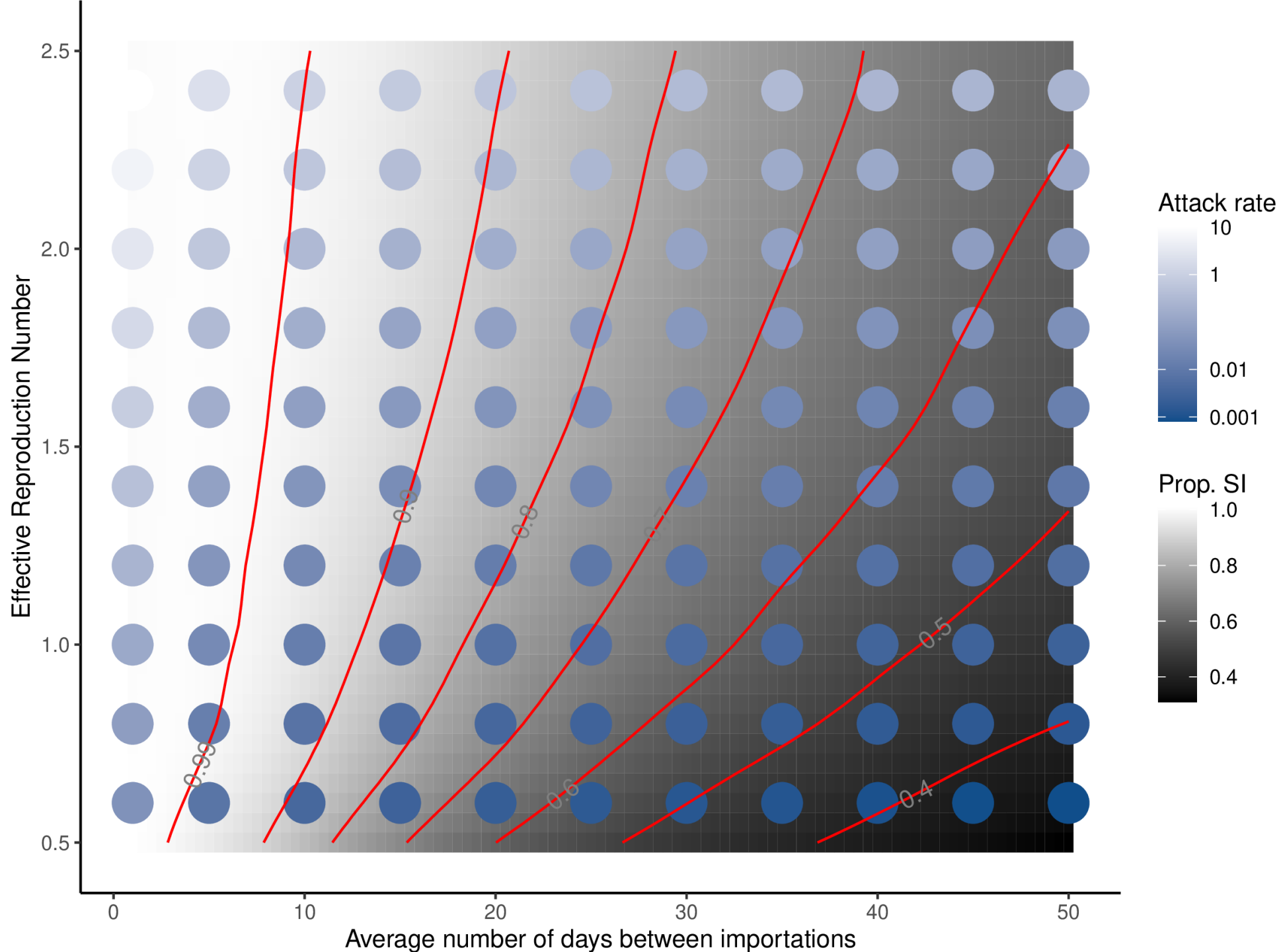
Importations

- In Ecology, importations are called *introductions* and have been studied for a while, because they are one of the drivers of evolution and, more recently, because of *invasive species*
- An importation occurs when an individual who acquired the infection in a jurisdiction makes their way to another jurisdiction while still infected with the disease
- Geographies greatly influence reasoning
    - At the country level, importations quickly become less relevant
    - Consider an isolated location of 500 people.. disease may become extinct then be reimported


Jurisdictions with new cases in past 21 days (%)
0
20
40
60
80
100
2020-07-01
2021-01-01
2021-07-01
Date
CAN (122)
MEX (2,454)
USA (3,243)


Importation
S
ΦS
L_1
εL_1
L_2
$(1-p)\varepsilon L_2$
$p\varepsilon L_2$
U_1
γU_1
U_2
γU_2
R_U
D_1
γD_1
D_2
$(1-\delta)\gamma D_2$
R_D
$\delta\gamma D_2$
M
Major outbreak
Minor outbreak
Unsuccessful importation
Time horizon 3 months


No importations
λ = 0. 01
λ = 0. 02
λ = 0. 03
λ = 0. 05
λ = 0. 10
λ = 0. 20
λ = 0. 50
λ = 1. 00
λ = 2. 00
λ = 10. 00
Incidence per 100,000
0
200
400
600
800
1000
0
50
100
150
Time (day)


Effective Reproduction Number
2.5
2.0
1.5
1.0
0.5
0
10
20
30
40
50
Average number of days between importations
0.99
0.9
0.8
0.6
0.5
0.4
Attack rate
10
1
0.01
0.001
Prop. SI
1.0
0.8
0.6
0.4

Spread of SARS-CoV-2 variants

J. Arino, P.-Y. Boëlle, E.M. Milliken & S. Portet. Risk of COVID-19 variant importation - How useful are travel control measures? Infectious Disease Modelling, 2021

S.P Otto, T. Day, J. Arino, C. Colijn *et al*. The origins and potential future of SARS-CoV-2 variants of concern in the evolving COVID-19 pandemic. Current Biology, 2021

Understanding variant dynamics and how to control it

- Suppose a *resident variant* is propagating in a population, say, the original wild type or, now, B.1.1.7
- A *novel variant* comes along, say B.1.617.2 (SARS-CoV-2 Delta) or B.1.1.529 (SARS-CoV-2 Omicron) that is more transmissible

Q:

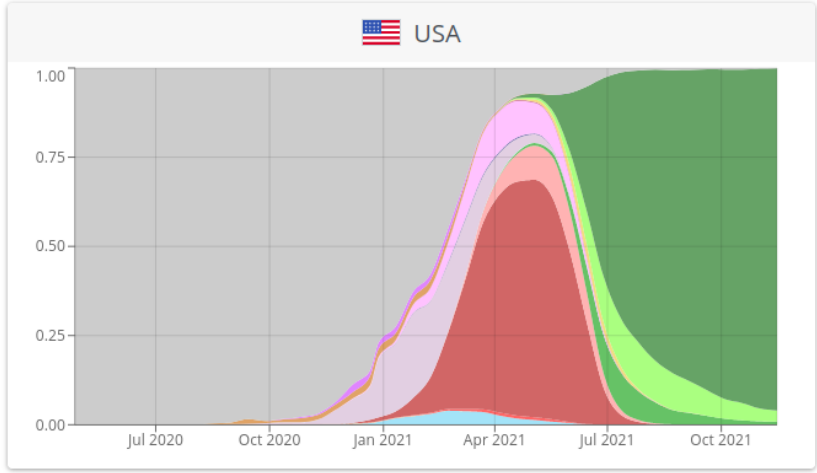
- How long until novel replaces resident variant in terms of propagation?
- What role do importations play in this?
- How does one diminish role of importations and how useful are measures used to do so?

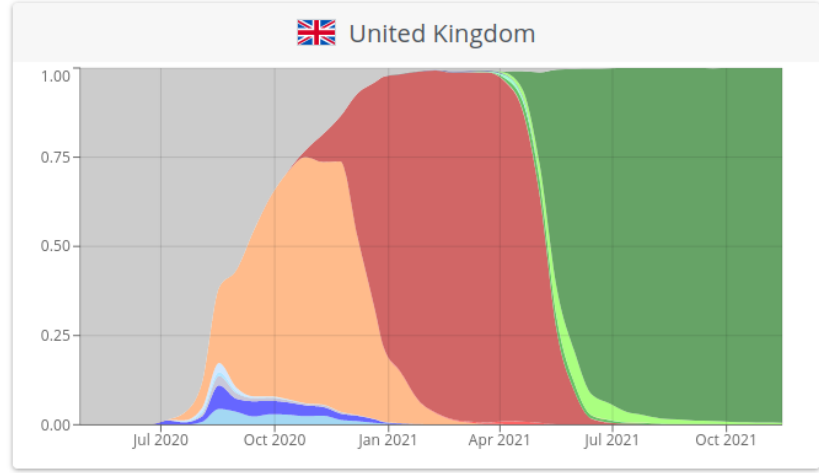
Variants

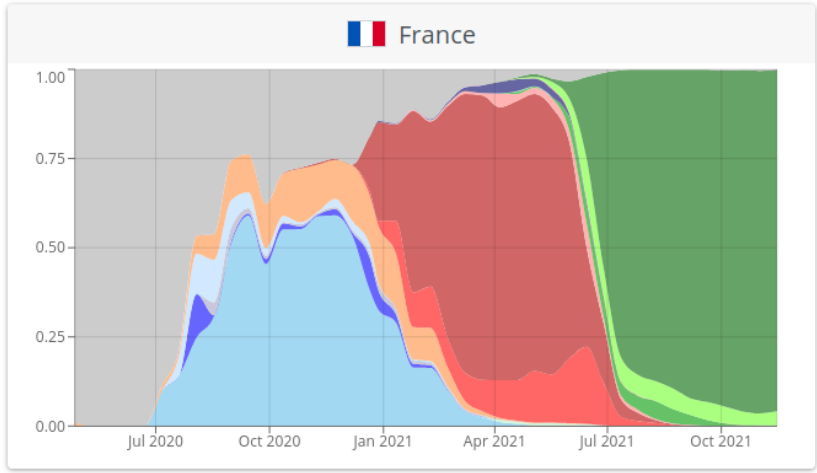
Select all Deselect all

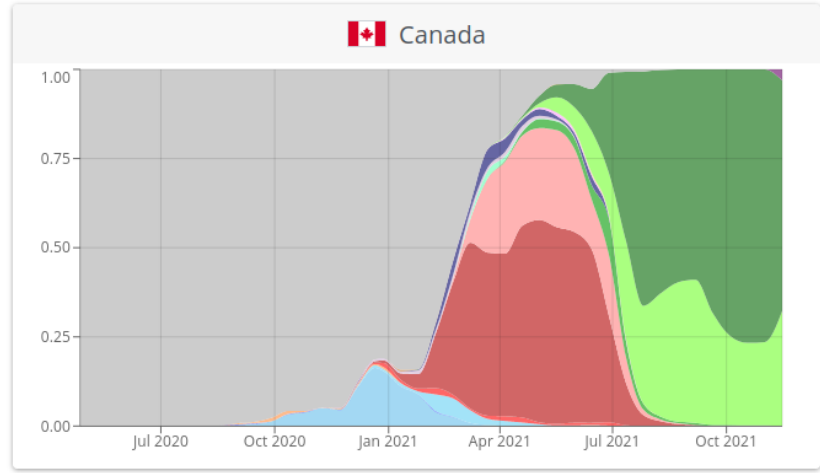
- 20I (Alpha, V1)
- 20H (Beta, V2)
- 20J (Gamma, V3)
- 21A (Delta)
- 21I (Delta)
- 21J (Delta)
- 21K (Omicron)
- 21B (Kappa)
- 21D (Eta)
- 21F (Iota)
- 21G (Lambda)
- 21H (Mu)
- 20B/S:732A
- 20A/S:126A
- 20E (EU1)
- 21C (Epsilon)
- 20A/S:439K
- S:677H.Robin1
- S:677P.Pelican
- 20A.EU2
- 20A/S:98F
- 20C/S:80Y
- 20B/S:626S
- 20B/S:1122L

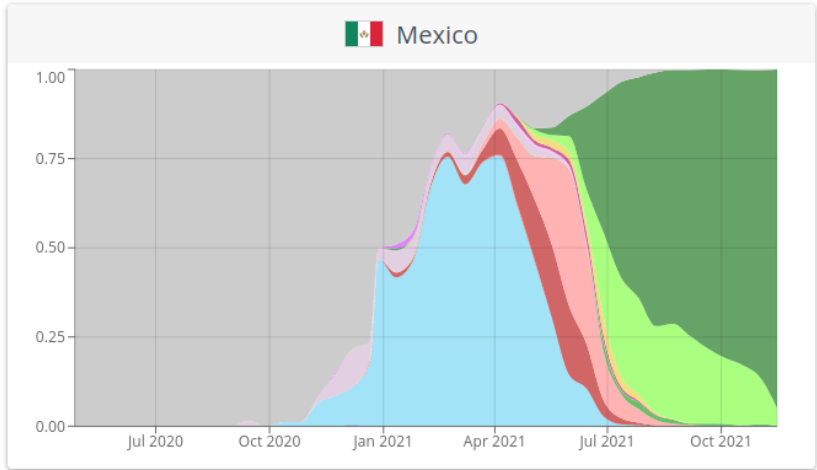
Countries

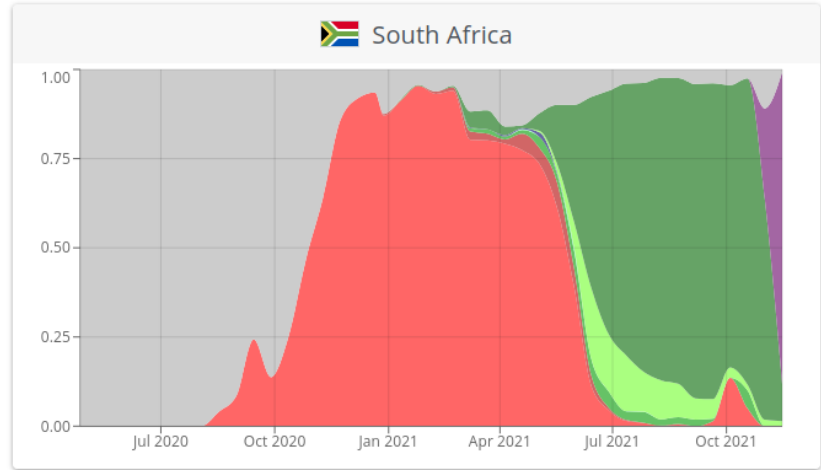


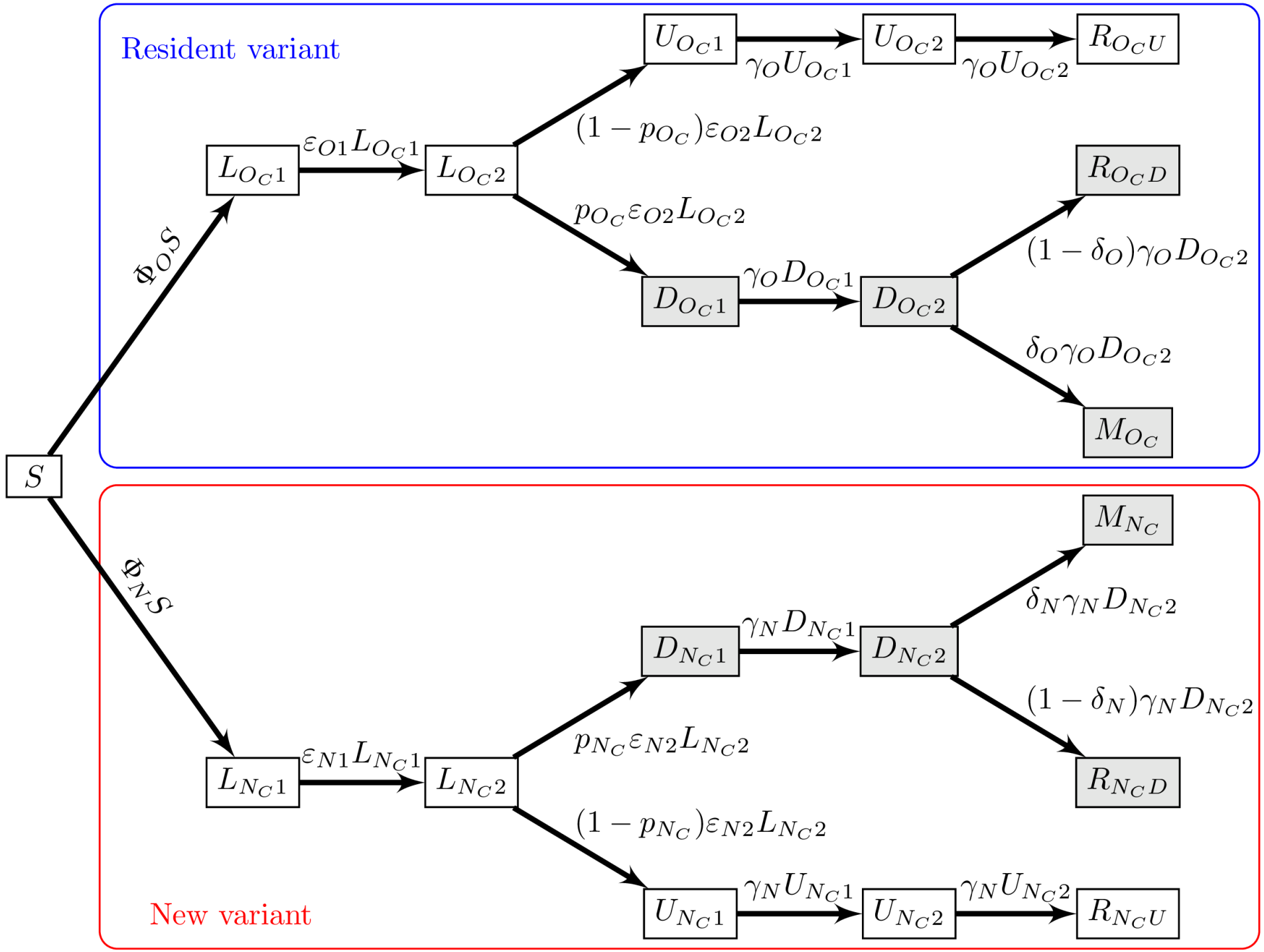


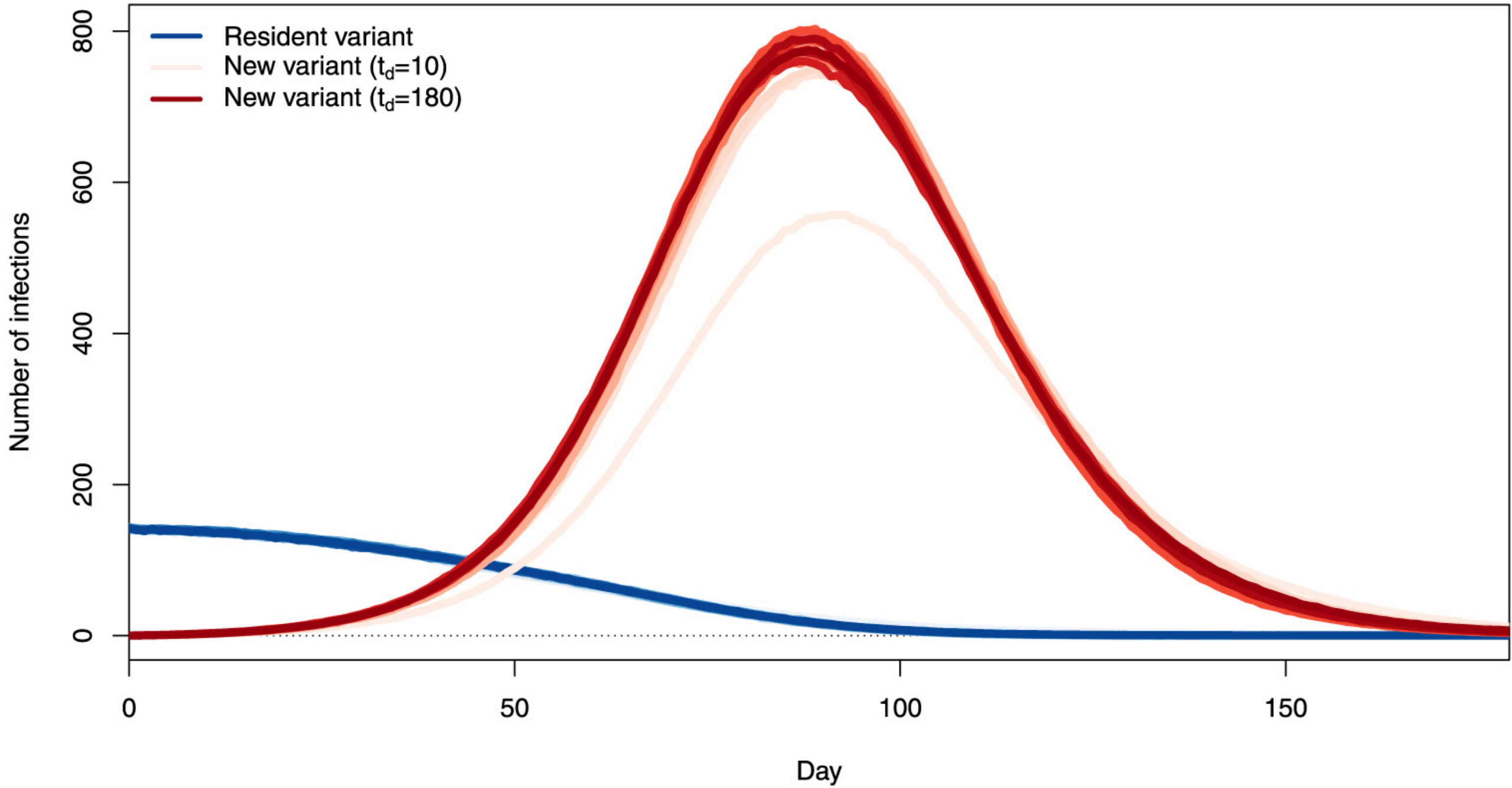


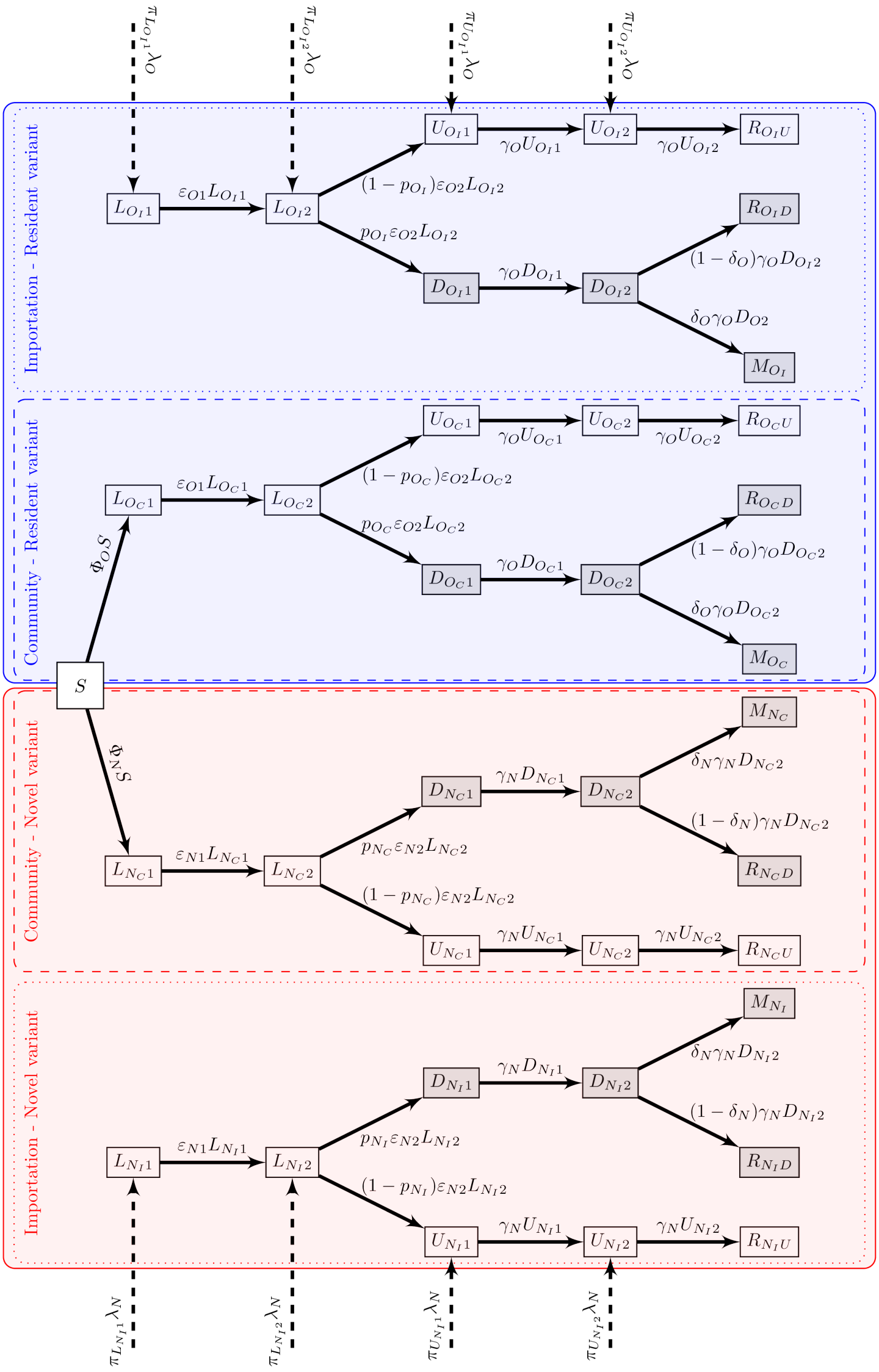




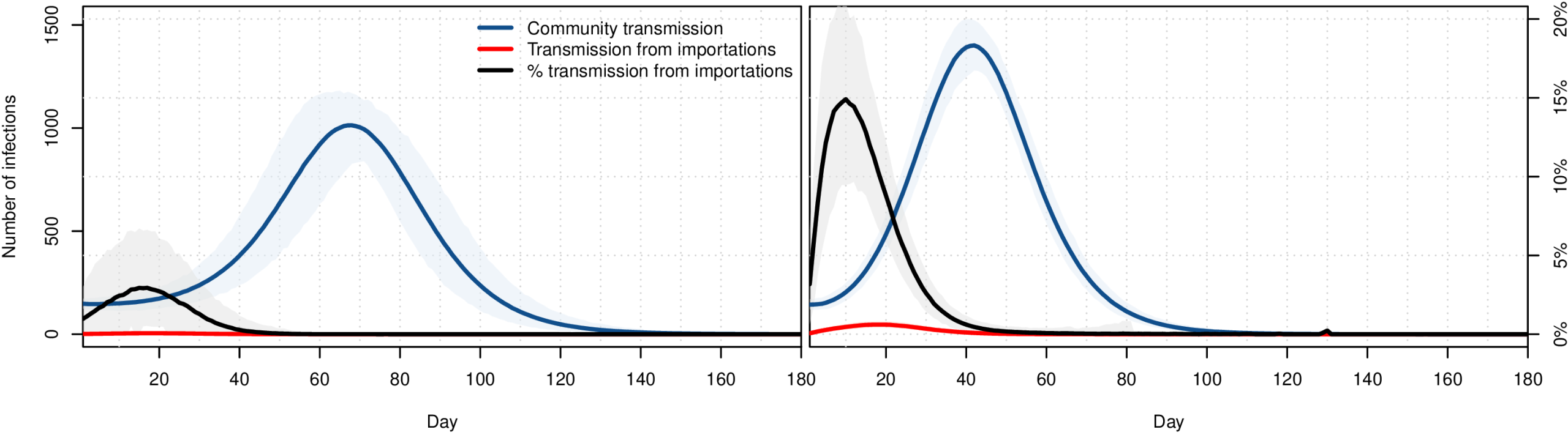



Resident variant
U_{OC1}
U_{OC2}
R_{OCU}
$\gamma_O U_{OC1}$
$\gamma_O U_{OC2}$
$(1-p_{OC})\varepsilon_{O2}L_{OC2}$
$\varepsilon_{O1}L_{OC1}$
L_{OC1}
L_{OC2}
R_{OCD}
$p_{OC}\varepsilon_{O2}L_{OC2}$
$\Phi_O S$
$\gamma_O D_{OC1}$
D_{OC1}
D_{OC2}
$(1-\delta_O)\gamma_O D_{OC2}$
$\delta_O\gamma_O D_{OC2}$
M_{OC}
S
$\Phi_N S$
M_{NC}
$\delta_N\gamma_N D_{NC2}$
$\gamma_N D_{NC1}$
D_{NC1}
D_{NC2}
$(1-\delta_N)\gamma_N D_{NC2}$
$p_{NC}\varepsilon_{N2}L_{NC2}$
$\varepsilon_{N1}L_{NC1}$
L_{NC1}
L_{NC2}
R_{NCD}
$(1-p_{NC})\varepsilon_{N2}L_{NC2}$
New variant
$\gamma_N U_{NC1}$
U_{NC1}
U_{NC2}
$\gamma_N U_{NC2}$
R_{NCU}


Resident variant
New variant (t_d=10)
New variant (t_d=180)
Number of infections
0
200
400
600
800
0
50
100
150
Day


Importation - Resident variant
Community - Resident variant
Community - Novel variant
Importation - Novel variant
$\pi_{L_{O_I1}}\lambda_O$
$\pi_{L_{O_I2}}\lambda_O$
$\pi_{U_{O_I1}}\lambda_O$
$\pi_{U_{O_I2}}\lambda_O$
L_{O_I1}
$\varepsilon_{O1}L_{O_I1}$
L_{O_I2}
$(1-p_{O_I})\varepsilon_{O2}L_{O_I2}$
$p_{O_I}\varepsilon_{O2}L_{O_I2}$
U_{O_I1}
$\gamma_O U_{O_I1}$
U_{O_I2}
$\gamma_O U_{O_I2}$
R_{O_IU}
D_{O_I1}
$\gamma_O D_{O_I1}$
D_{O_I2}
R_{O_ID}
$(1-\delta_O)\gamma_O D_{O_I2}$
$\delta_O\gamma_O D_{O2}$
M_{O_I}
S
$\Phi_O S$
L_{O_C1}
$\varepsilon_{O1}L_{O_C1}$
L_{O_C2}
$(1-p_{O_C})\varepsilon_{O2}L_{O_C2}$
$p_{O_C}\varepsilon_{O2}L_{O_C2}$
U_{O_C1}
$\gamma_O U_{O_C1}$
U_{O_C2}
$\gamma_O U_{O_C2}$
R_{O_CU}
D_{O_C1}
$\gamma_O D_{O_C1}$
D_{O_C2}
R_{O_CD}
$(1-\delta_O)\gamma_O D_{O_C2}$
$\delta_O\gamma_O D_{O_C2}$
M_{O_C}
S
$S^{N}\Phi$
L_{N_C1}
$\varepsilon_{N1}L_{N_C1}$
L_{N_C2}
$p_{N_C}\varepsilon_{N2}L_{N_C2}$
$(1-p_{N_C})\varepsilon_{N2}L_{N_C2}$
D_{N_C1}
$\gamma_N D_{N_C1}$
D_{N_C2}
M_{N_C}
$\delta_N\gamma_N D_{N_C2}$
$(1-\delta_N)\gamma_N D_{N_C2}$
R_{N_CD}
U_{N_C1}
$\gamma_N U_{N_C1}$
U_{N_C2}
$\gamma_N U_{N_C2}$
R_{N_CU}
L_{N_I1}
$\varepsilon_{N1}L_{N_I1}$
L_{N_I2}
$p_{N_I}\varepsilon_{N2}L_{N_I2}$
$(1-p_{N_I})\varepsilon_{N2}L_{N_I2}$
D_{N_I1}
$\gamma_N D_{N_I1}$
D_{N_I2}
M_{N_I}
$\delta_N\gamma_N D_{N_I2}$
$(1-\delta_N)\gamma_N D_{N_I2}$
R_{N_ID}
U_{N_I1}
$\gamma_N U_{N_I1}$
U_{N_I2}
$\gamma_N U_{N_I2}$
R_{N_IU}
$\pi_{L_{N_I1}}\lambda_N$
$\pi_{L_{N_I2}}\lambda_N$
$\pi_{U_{N_I1}}\lambda_N$
$\pi_{U_{N_I2}}\lambda_N$

Variant importation in a metapopulation model



Left: low movement rate. Right: higher movement rate

Measures to control spatial spread

- Almost exclusively attacked from the perspective of would-be importer

In practice:

- Travel interruptions
- Quarantine

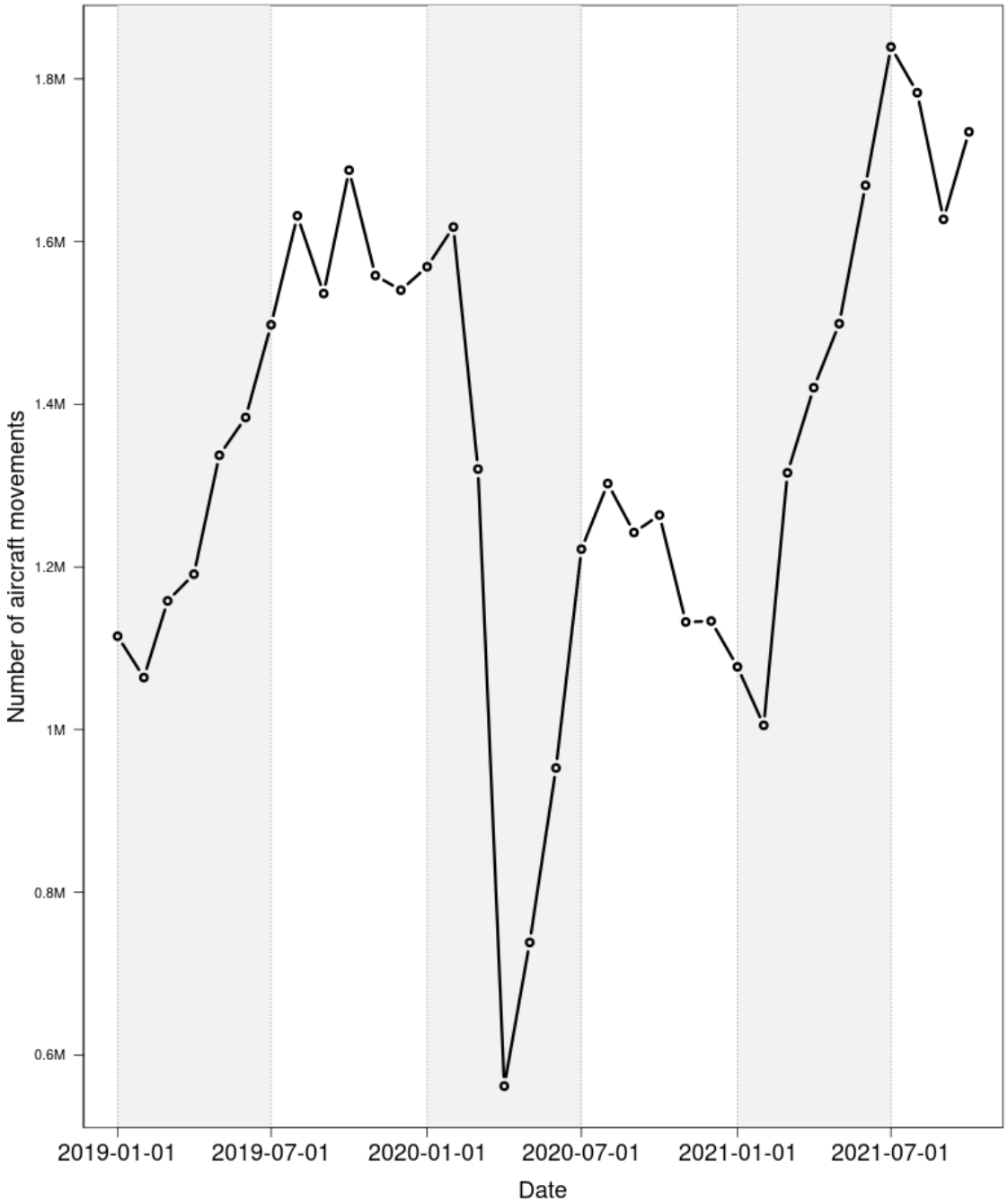
Role of transport restrictions

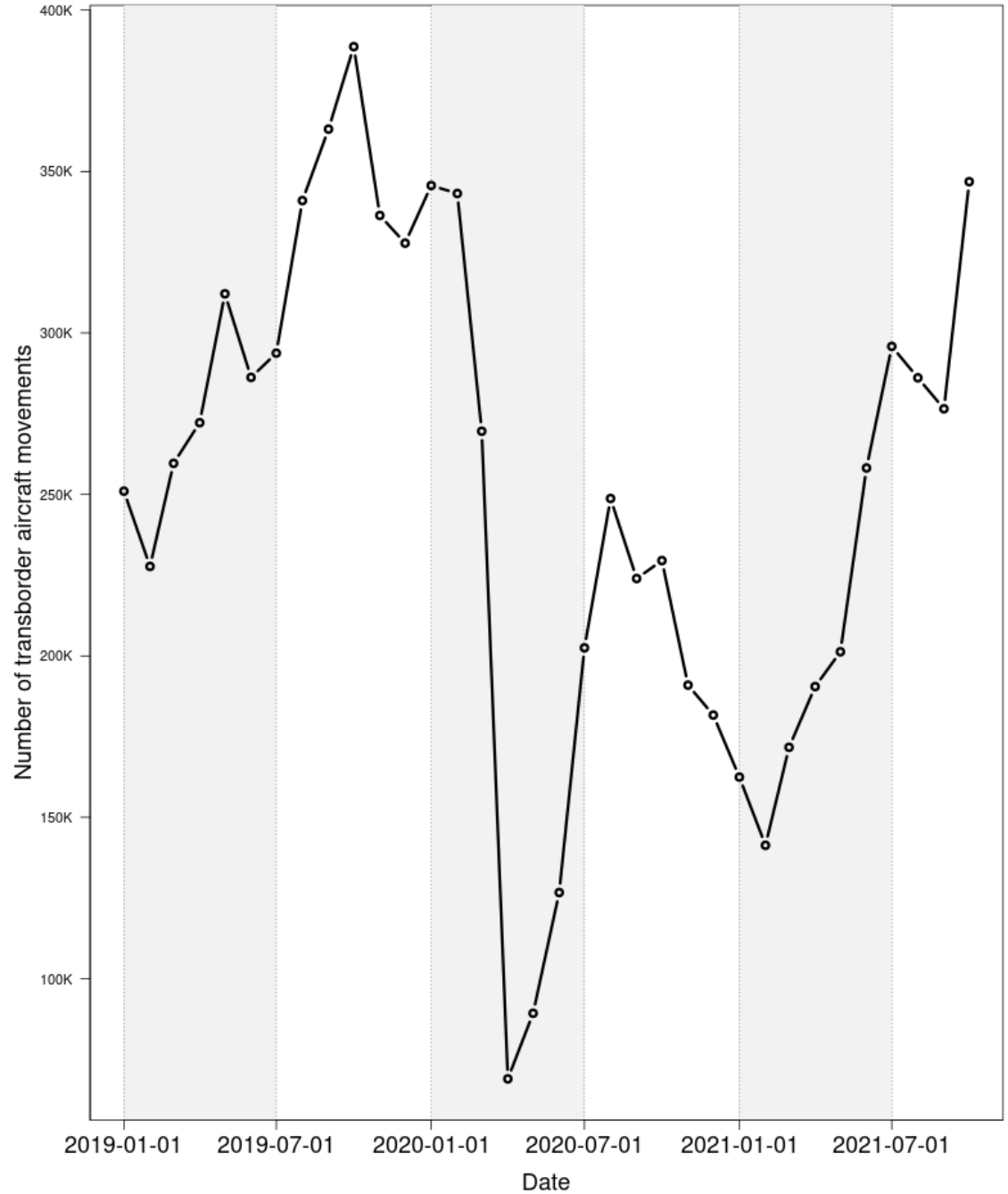
J. Arino, P.-Y. Boëlle, E.M. Milliken & S. Portet. Risk of COVID-19 variant importation - How useful are travel control measures? Infectious Disease Modelling, 2021

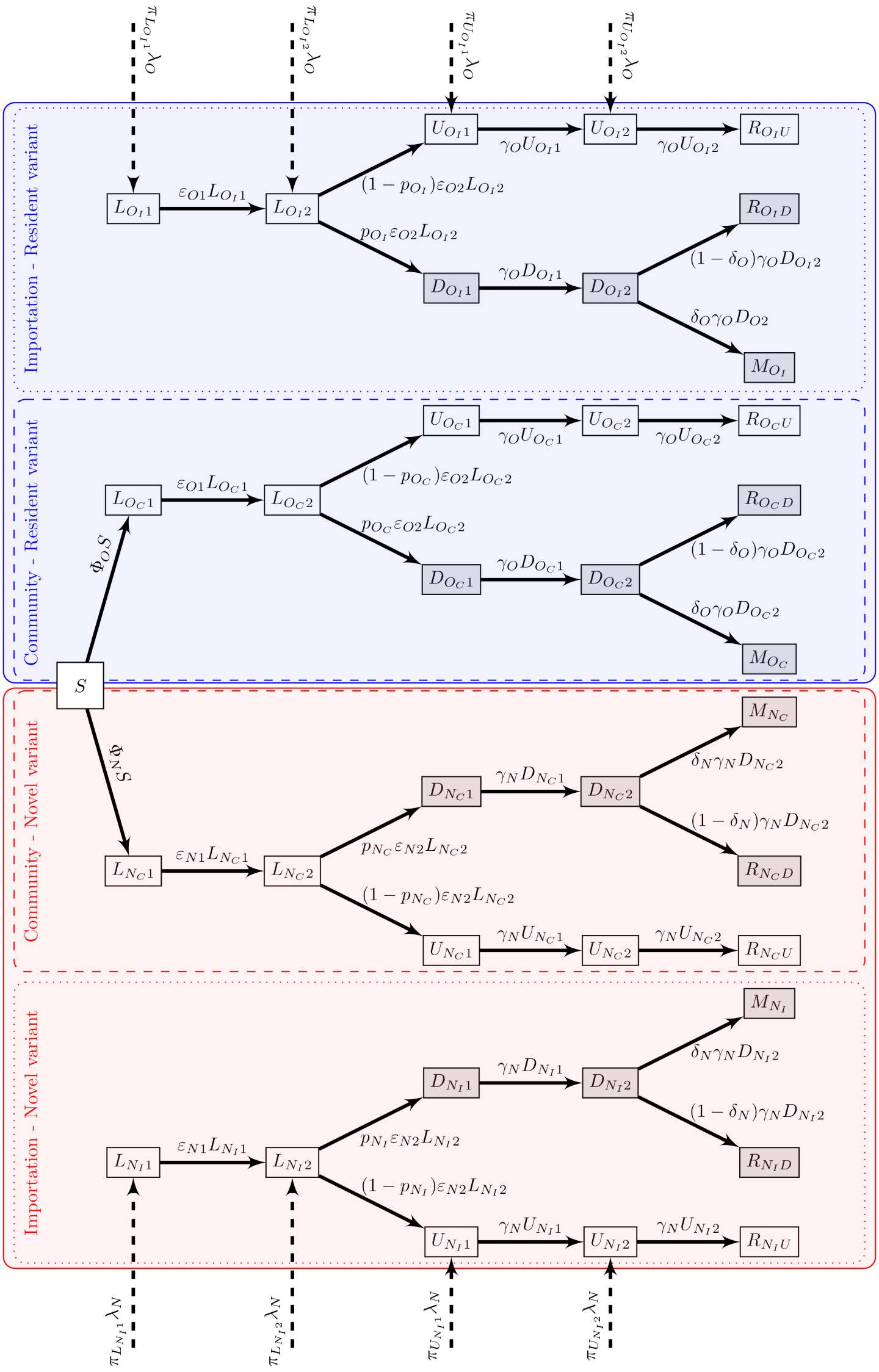
Mur de la Peste in Cabrières-d’Avignon

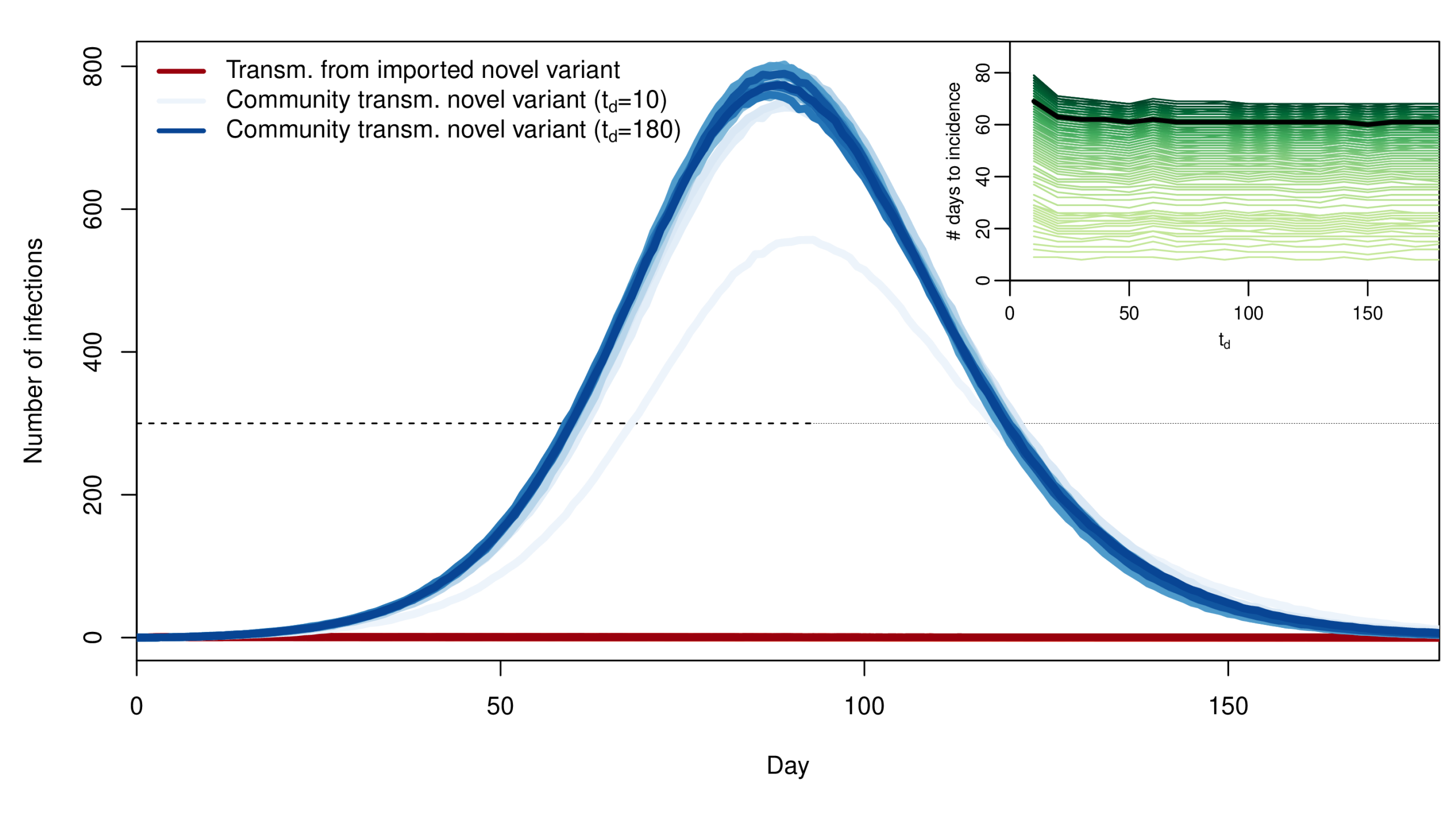
Interruption of travel

Country	Date travel suspension	Date first case
Seychelles	2020-03-03	2020-03-14
El Salvador	2020-03-17	2020-03-18
Cape Verde	2020-03-17	2020-03-20
Sudan	2020-03-17	2020-04-05
Marshall Islands	2020-04-22	2020-10-29
Vanuatu	2020-03-20	2020-11-11
North Korea	2020-01-21	Unreported
Turkmenistan	2020-03-20	Unreported
Tuvalu	2020-03-26	


1.8M
1.6M
1.4M
1.2M
1M
0.8M
0.6M
Number of aircraft movements
2019-01-01
2019-07-01
2020-01-01
2020-07-01
2021-01-01
2021-07-01
Date


400K
350K
300K
250K
200K
150K
100K
Number of transborder aircraft movements
2019-01-01
2019-07-01
2020-01-01
2020-07-01
2021-01-01
2021-07-01
Date


Importation - Resident variant
Community - Resident variant
Community - Novel variant
Importation - Novel variant
$\pi_{L_{O_I1}}\lambda_O$
$\pi_{L_{O_I2}}\lambda_O$
$\pi_{U_{O_I1}}\lambda_O$
$\pi_{U_{O_I2}}\lambda_O$
L_{O_I1}
$\varepsilon_{O1}L_{O_I1}$
L_{O_I2}
$(1-p_{O_I})\varepsilon_{O2}L_{O_I2}$
$p_{O_I}\varepsilon_{O2}L_{O_I2}$
U_{O_I1}
$\gamma_O U_{O_I1}$
U_{O_I2}
$\gamma_O U_{O_I2}$
R_{O_IU}
D_{O_I1}
$\gamma_O D_{O_I1}$
D_{O_I2}
R_{O_ID}
$(1-\delta_O)\gamma_O D_{O_I2}$
$\delta_O\gamma_O D_{O2}$
M_{O_I}
S
$\Phi_O S$
L_{O_C1}
$\varepsilon_{O1}L_{O_C1}$
L_{O_C2}
$(1-p_{O_C})\varepsilon_{O2}L_{O_C2}$
$p_{O_C}\varepsilon_{O2}L_{O_C2}$
U_{O_C1}
$\gamma_O U_{O_C1}$
U_{O_C2}
$\gamma_O U_{O_C2}$
R_{O_CU}
D_{O_C1}
$\gamma_O D_{O_C1}$
D_{O_C2}
R_{O_CD}
$(1-\delta_O)\gamma_O D_{O_C2}$
$\delta_O\gamma_O D_{O_C2}$
M_{O_C}
S
$S^{N}\Phi$
L_{N_C1}
$\varepsilon_{N1}L_{N_C1}$
L_{N_C2}
$p_{N_C}\varepsilon_{N2}L_{N_C2}$
$(1-p_{N_C})\varepsilon_{N2}L_{N_C2}$
D_{N_C1}
$\gamma_N D_{N_C1}$
D_{N_C2}
M_{N_C}
$\delta_N\gamma_N D_{N_C2}$
$(1-\delta_N)\gamma_N D_{N_C2}$
R_{N_CD}
U_{N_C1}
$\gamma_N U_{N_C1}$
U_{N_C2}
$\gamma_N U_{N_C2}$
R_{N_CU}
L_{N_I1}
$\varepsilon_{N1}L_{N_I1}$
L_{N_I2}
$p_{N_I}\varepsilon_{N2}L_{N_I2}$
$(1-p_{N_I})\varepsilon_{N2}L_{N_I2}$
D_{N_I1}
$\gamma_N D_{N_I1}$
D_{N_I2}
M_{N_I}
$\delta_N\gamma_N D_{N_I2}$
$(1-\delta_N)\gamma_N D_{N_I2}$
R_{N_ID}
U_{N_I1}
$\gamma_N U_{N_I1}$
U_{N_I2}
$\gamma_N U_{N_I2}$
R_{N_IU}
$\pi_{L_{N_I1}}\lambda_N$
$\pi_{L_{N_I2}}\lambda_N$
$\pi_{U_{N_I1}}\lambda_N$
$\pi_{U_{N_I2}}\lambda_N$


Transm. from imported novel variant
Community transm. novel variant (t_d=10)
Community transm. novel variant (t_d=180)
Number of infections
0
200
400
600
800
0
50
100
150
Day
days to incidence
0
20
40
60
80
0
50
100
150
t_d

Effect of quarantine

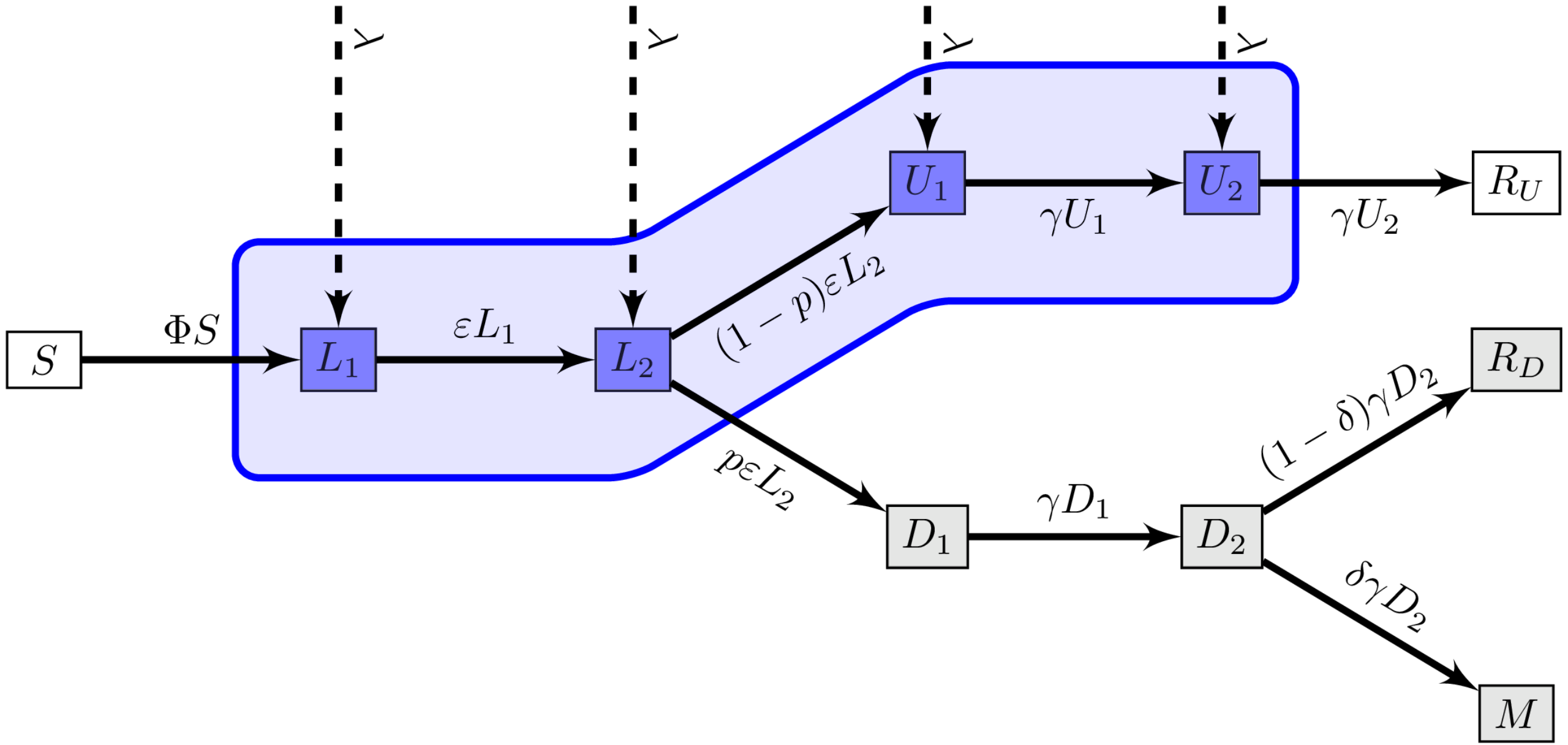
J. Arino, N. Bajeux, S. Portet & J. Watmough. Quarantine and the risk of COVID-19 importation. Epidemiology & Infection, 2020

J. Arino, P.-Y. Boëlle, E.M. Milliken & S. Portet. Risk of COVID-19 variant importation - How useful are travel control measures? Infectious Disease Modelling, 2021

Quarantine ≠ Isolation

- *Quarantine* is indiscriminate and applies to all incoming flux
- *Isolation* is imposed to known or suspected cases and known contacts
- First used in (the lazzarettos of) Dubrovnik in 1377
- Name comes from Venitian *quarantena*

Lazzaretto vecchio


γ
γ
γ
γ
S
ΦS
L_1
εL_1
L_2
$(1-p)\varepsilon L_2$
$p\varepsilon L_2$
U_1
γU_1
U_2
γU_2
R_U
D_1
γD_1
D_2
$(1-\delta)\gamma D_2$
R_D
$\delta\gamma D_2$
M

COVID-19 quarantine efficacy calculator

Duration of quarantine (days):

0 5 40

0 4 8 12 16 20 24 28 32 36 40

Avg. incubation period (days):

1 4 10

1 1.9 2.8 3.7 4.6 5.5 6.4 7.3 8.2 9.1 10

Avg. infectious period (days):

1 6 20

1 2.9 4.8 6.7 8.6 10.5 12.4 14.3 16.2 18.1 20

Prop. detected cases:

0 0.5 1

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Effect of quarantine | Quarantine efficacy

Effect of quarantine on importation rates

$1/\lambda$ the mean time between case importations, $1/\lambda_q$ the mean quarantine-regulated time between case importations, c the efficacy of quarantine (in %). Then

$$\lambda_q = (100 - c) \times \lambda$$

Suppose $1/\lambda = 5$ days and efficacy of quarantine is 90% at 7 days and 98% at 14 days, respectively

Then $1/\lambda_q = 50$ and 250 days, respectively

Lessons learned & key questions/knowledge gaps

Lessons learned

- Airport screening sometimes worked to detect the first imports
- Travel interruptions work .. sometimes (e.g., ISL, NZL, CAN-NL)
- Travel interruptions often do not work (e.g., world $\setminus$ very few)
- Governments like travel interruptions regardless
- Quarantine seems to work quite well but needs to be applied homogeneously
- Open Data has finally landed in public health. Still some issues (e.g., Canadian data), but we're moving in the right direction. Also saw emergence of scientist/journalistic/citizen data collection and dissemination initiatives

Key questions/knowledge gaps

- How to get governments to understand that a pandemic is a **global** phenomenon with **local** "phenotypes", so that uncoordinated unilateral travel policies have virtually no chance of success (*treat the symtoms, not the cause*)
- How to apprehend/model the absolutely colossal amount of mobility taking place and the not less consequent variety of transport modalities and purposes
- What are the necessary conditions for travel interruptions to work?
- Because of scapegoating, the borders were closed *in theory*. However, because of .. real life, they were not *in practice*. How closed is closed?

Arrival into CAN from 2020-04-01 to 2021-03-31

(border was "closed")

Traveller characteristics	Total
Total non-resident travellers	1,491,233
Total Canadian residents	3,653,592
Total other travellers	5,963,285
Total international travellers	11,108,110

80/100K/day on average (678/100K/day 2019-04 $\rightarrow$ 2020-03)

Key questions/knowledge gaps (cont.)

- Effect of heterogeity of vaccination methods/protocols (vaccine type/number of doses/ages)
- What is the effect of local vaccine uptake discrepancies?
- Variants emerge typically in high propagation areas. How will the vaccine divide play into this?

Manitoba COVID-19 Vaccinations

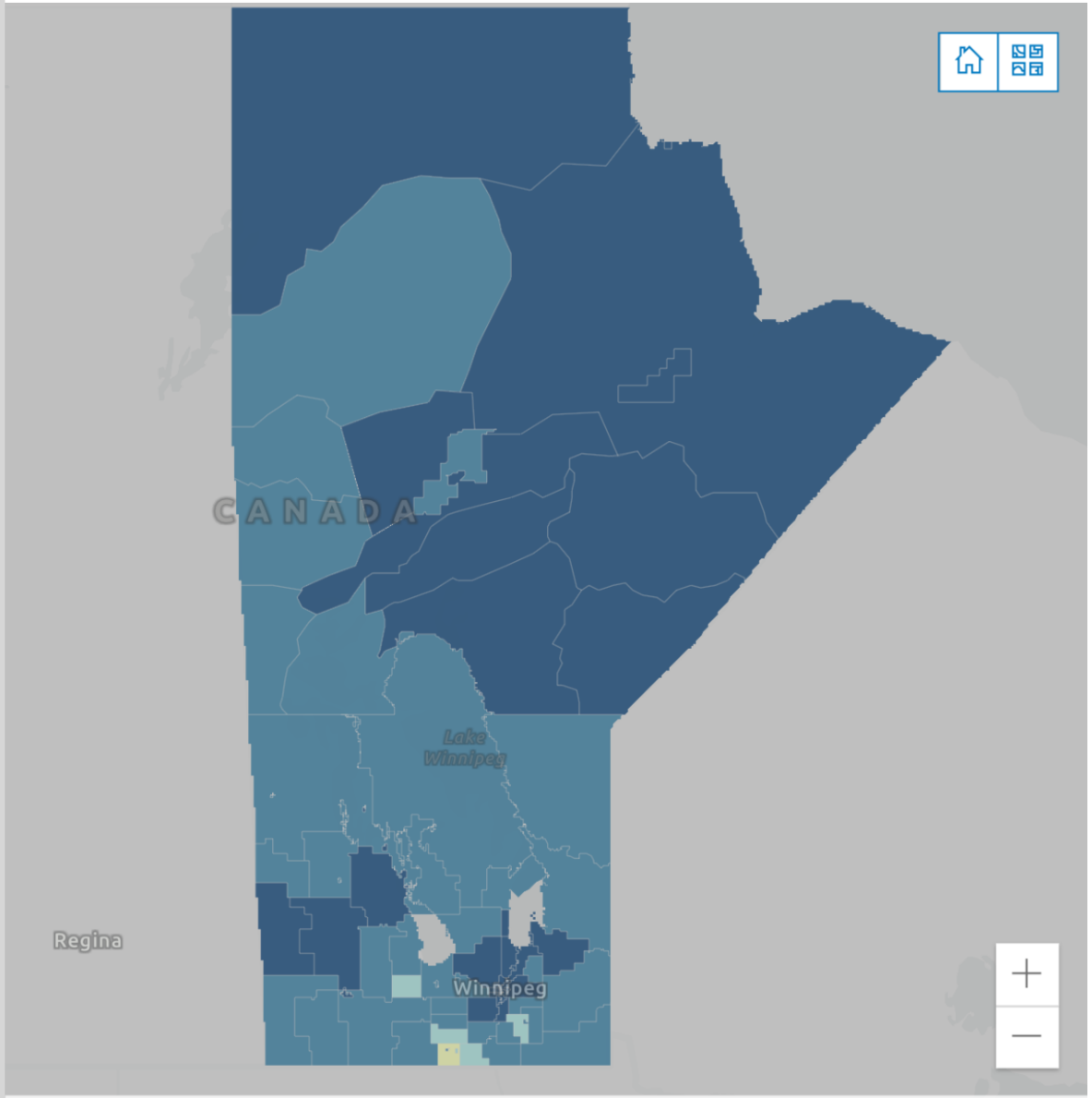
Vaccine Uptake by District

Rate of Uptake

- > 80 - 100%
- > 60 - 80%
- > 40 - 60%
- > 20 - 40%
- 0 - 20%

Vaccination Uptake Rate by Health District/Winnipeg Community

Percentage of Manitobans 12 years +

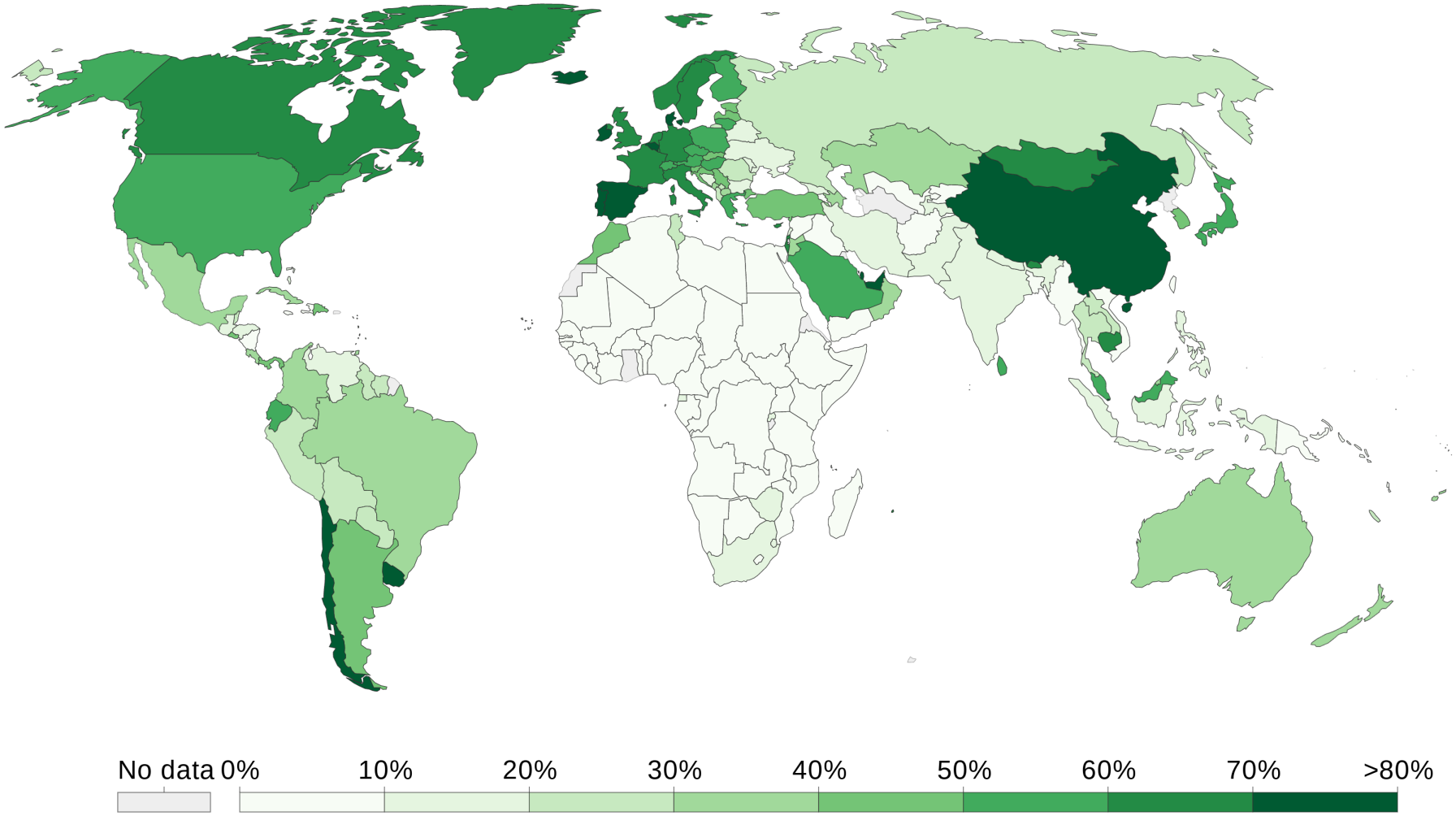


Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada | Manitoba G… Powered by Esri

Share of the population fully vaccinated against COVID-19

Total number of people who received all doses prescribed by the vaccination protocol, divided by the total population of the country.

Our World in Data



Source: Official data collated by Our World in Data – Last updated 20 September 2021, 18:00 (London time)
Note: Alternative definitions of a full vaccination, e.g. having been infected with SARS-CoV-2 and having 1 dose of a 2-dose protocol, are ignored to maximize comparability between countries.

In conclusion

Space is a fundamental component of the epidemic spread process and **cannot** be ignored, both in modelling **and** in public health decision making

Merci / Miigwech / Thank you