COVID Model Projections

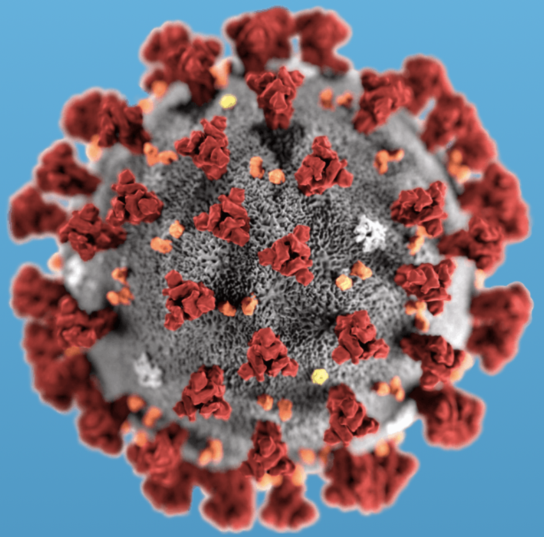
April 14, 2021

BC COVID-19 Modelling Group

About BC COVID-19 Modelling Group

The BC COVID-19 Modelling Group works on rapid response modelling of the COVID-19 pandemic, with a special focus on British Columbia and Canada.

The interdisciplinary Group was convened by Caroline Colijn (SFU) and Dan Coombs (UBC) with support from the Pacific Institute for the Mathematical Sciences.



https://bccovid-19group.ca

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Independent and freely offered advice,
using a diversity of modelling approaches.

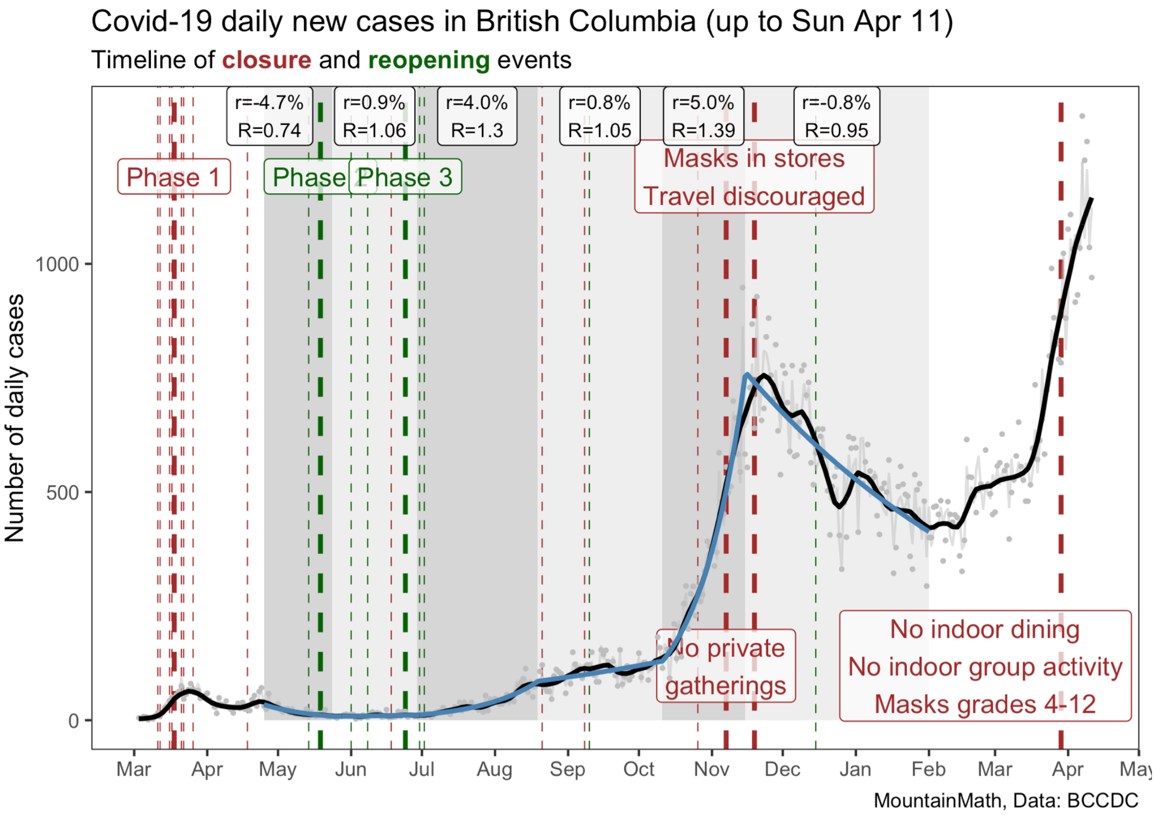
Key messages

- Growth of variants of concern (B.1.1.7 and P.1) has driven recent rise in cases
- Transmission must be reduced by ~40% to control case growth (relative to March 2021 levels)
- Hospitalization numbers are projected to rise above capacity in May, unless virus transmission is brought under control
- Vaccination program needs to swiftly target those with the most contacts so that infection and hospitalization rates can be reduced over the next 2-3 months

State of the COVID-19 Pandemic in BC

Most of the pandemic in BC is well-described by long periods of constant growth or decline (blue curves) delineated by changes in public health measures.

Public health measures work.



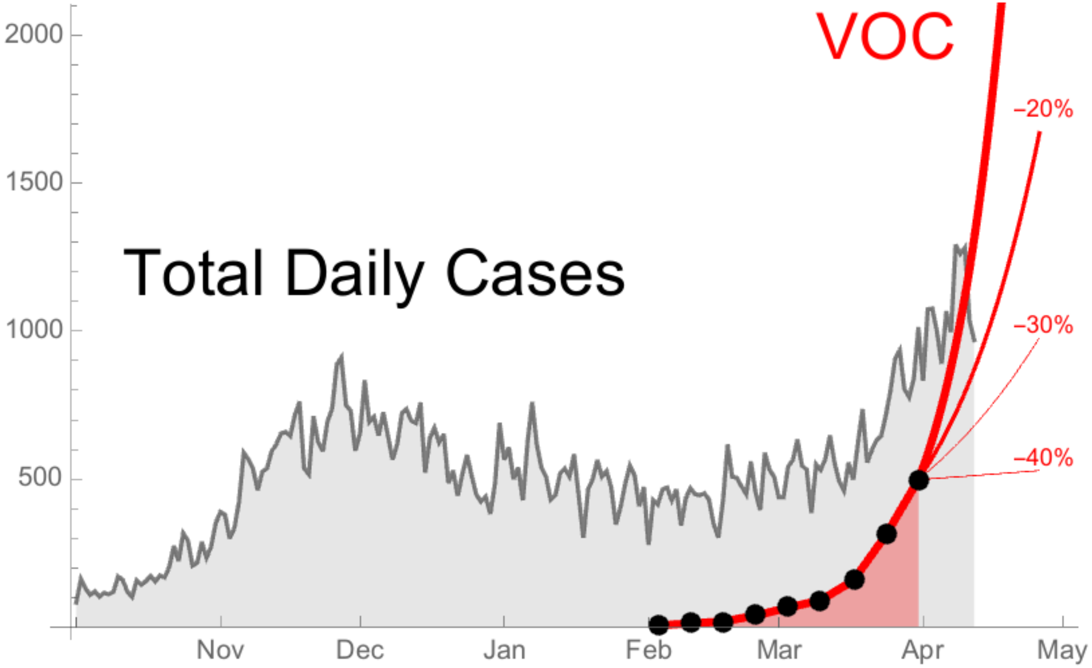
Source (J. von Bergmann) Case data from BC COVID-19 Database (http://www.bccdc.ca/health-info/diseases-conditions/covid-19/data). Vertical lines give dates of public health measures (major as thick lines, minor as thin lines). Grey dots are raw case counts, grey lines is cases abused for weekly pattern, black STL trend line and blue fitted periods of constant exponential growth.

Recent trend in case numbers

Recent surge in case numbers is due to rise in B.1.1.7 and P.1 variants of concern (VOC).

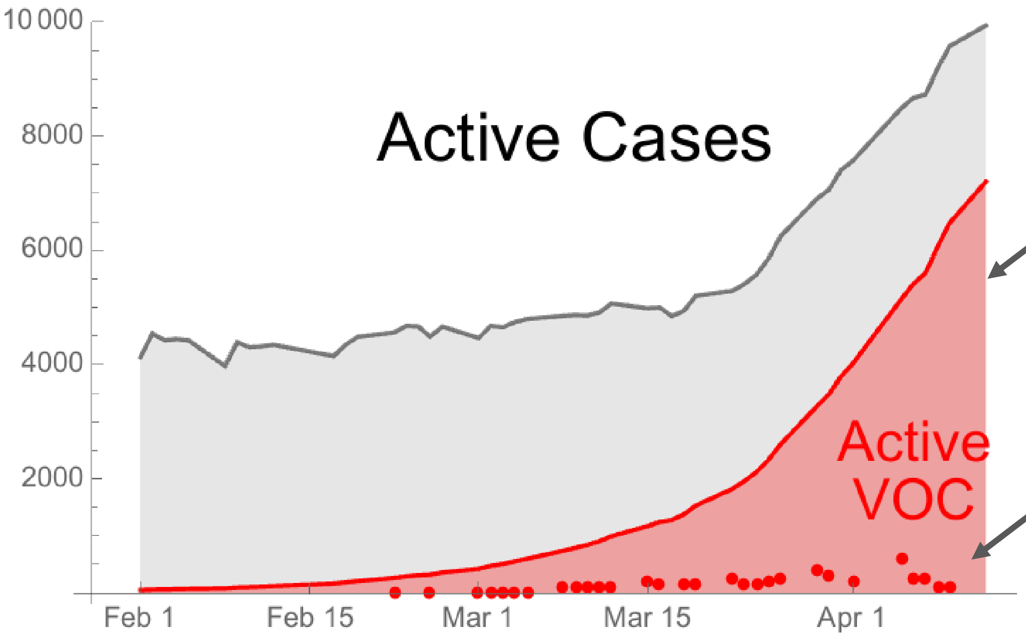
VOC grew exponentially in February and March, doubling every 8.6 days (95%CI: 7.9-9.3 days).

VOC transmission must be reduced by an additional ~40% from March levels to halt growth (thinner red curves are illustrations only).



Source (S. Otto). Case data from Joint Statements (https://archive.news.gov.bc.ca; April 9, 2021). VOC data from BCCDC (April 7, 2021). VOC are typed by PCR assays for S:N501Y ("presumptive VOC"). Starting with the point prevalence assay (epiweek 5), average daily case count in each epiweek is multiplied by the proportion of VOC observed that week (black dots). Exponential growth rate (thick red curve, r = 0.081) was estimated by a linear fit to log(data). Growth rate (r = 0.081) was used to calculate the reproductive number R_t = exp(6.5 r) = 1.69 assuming a 6.5 day generation (Volz et al. 2021). R_t was then used to determine impact of reducing transmission (thin red curves).

Recent trend in active case numbers

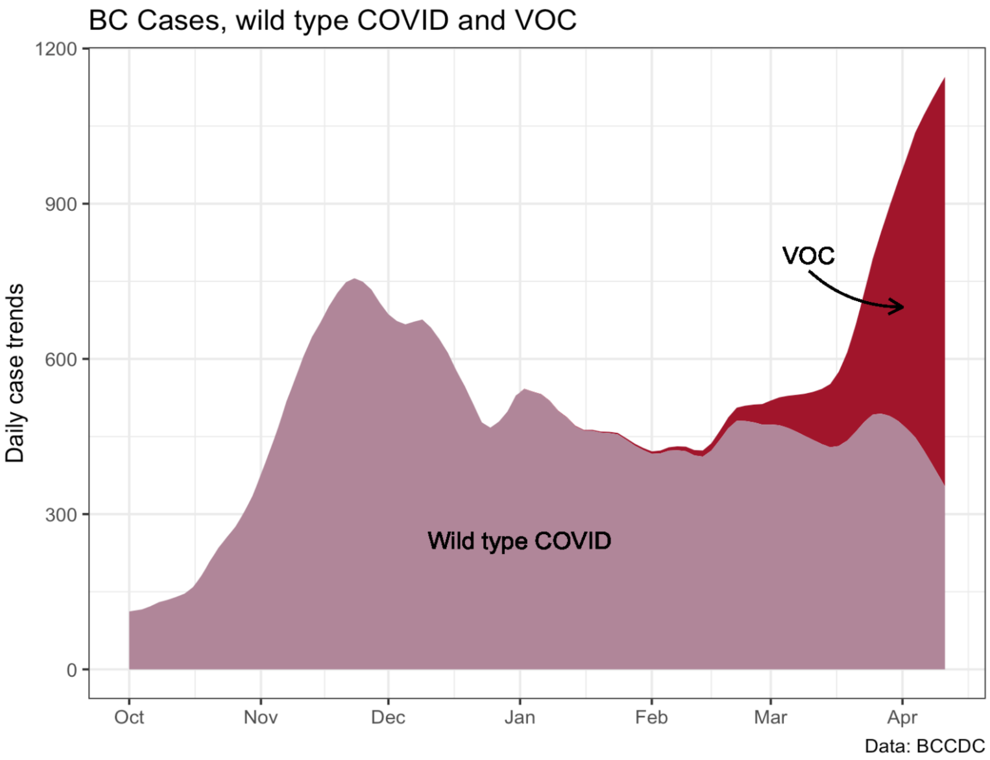


Number of active VOC cases (red region) inferred from the percent VOC

BC's Joint Statements report number of active VOC cases that remain active after confirmation by whole genome sequencing (red dots).

Source (S. Otto). Active case numbers from Joint Statements through April 9, 2021 (https://archive.news.gov.bc.ca). VOC data from BCCDC (April 7, 2021) provide % of cases that were VOC by week (see slide 5). These data were fit by a logistic function to estimate percent VOC by day (see Appendix), which was then multiplied by the number of active cases to estimate the active number of VOC cases (red shaded region).

Recent trend in case numbers (smoothed fit)

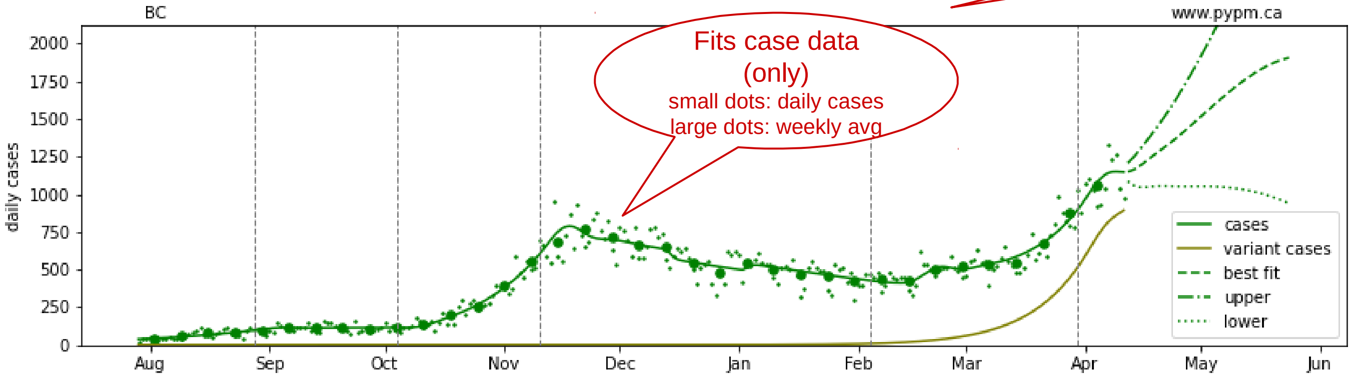


Rise in VOC was predicted and aligns well with what has been seen in other jurisdictions.

Source (J. Bergmann). Case data from BC COVID-19 Database (http://www.bccdc.ca/health-info/diseases-conditions/covid-19/data) and smoothed using STL trend line that removes day-of-the-week effects. VOC data from BCCDC (April 7, 2021).

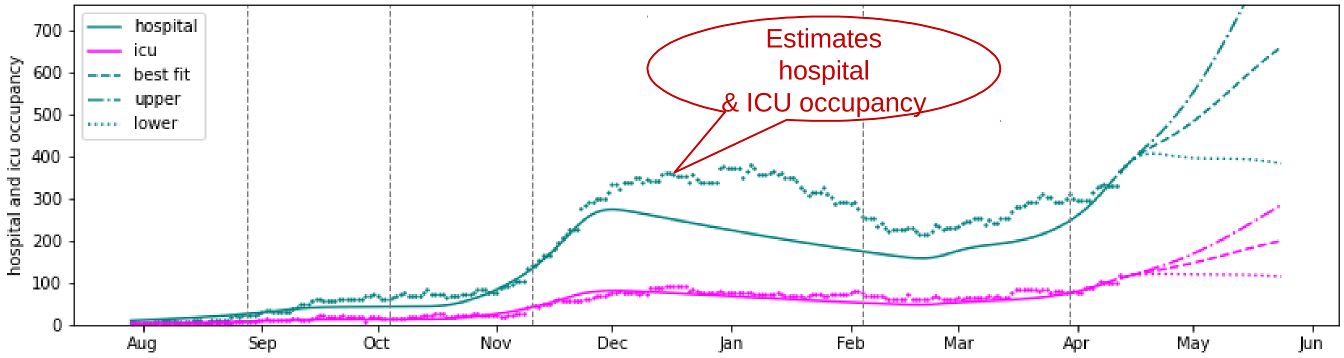
Model fit to case data (up to April 11)

Also finds long periods with constant transmission rates (between vertical lines)



Shows best fit of model to case data, assuming a change to transmission rates occurred on March 30.

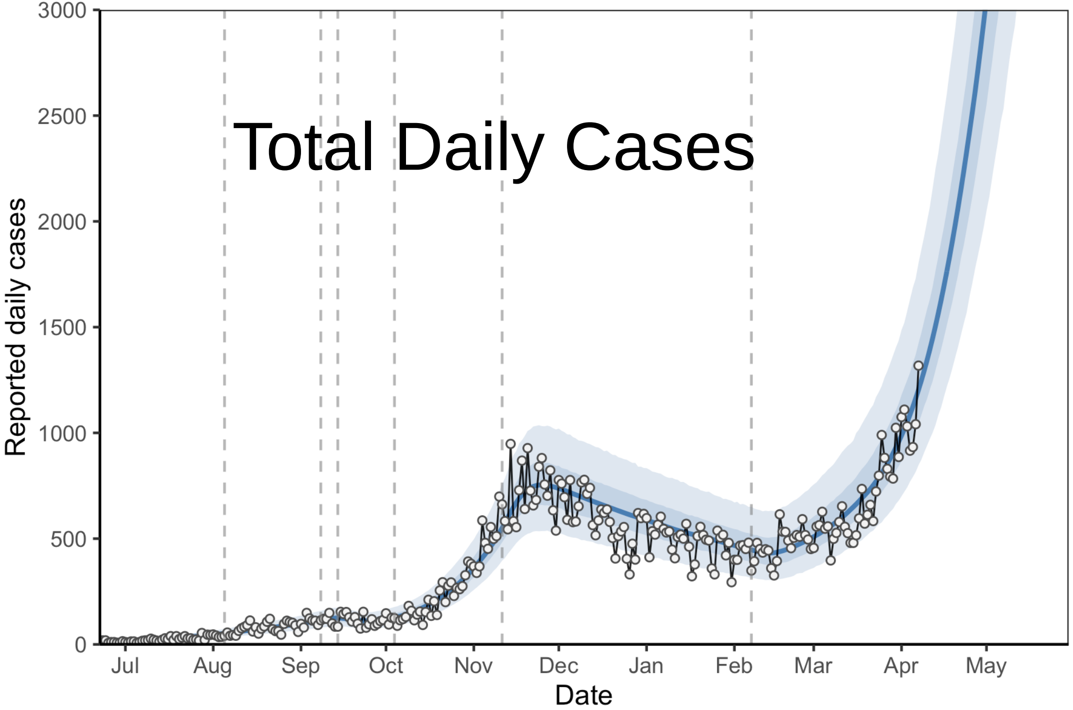
- Many possible trajectories are consistent with data - two (upper and lower) are shown to indicate current uncertainty.



Includes vaccination, removing vaccinated individuals from susceptible class following a delay (median 16 days).

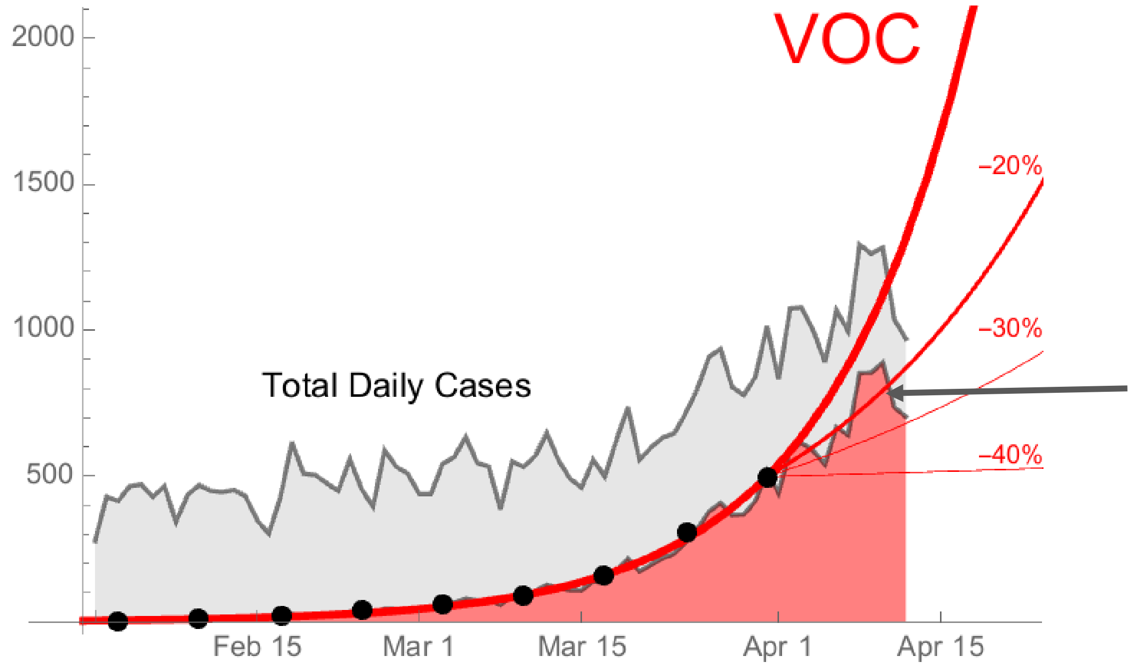
Source (D. Karlen). See www.pypm.ca. Assumes homogeneous mixing (no age structure). Assumes vaccination rate of 1st doses increases from 17,000/day (current rate) to 30,000/day (starting on April 13). Vaccination model benchmarked with data from Israel: see this link.

Near-term incidence projection



Source (E. Are, C. Colijn). Active case numbers projected forward, accounting for VOC data from BCCDC (April 7, 2021). These data provide % of cases that were VOC by week (see slide 5). These data were fit by a logistic function to estimate percent VOC by day (see Appendix). Assuming a 40% increase in transmissibility (consistent with the estimated selection *s* in the Appendix), the percent VOC is used to create an overall reproduction number *R* for the virus population. *R* changes in time as the VOC rises in frequency. The social distancing parameter (among others) is estimated to fit the data using the 'covidseir' R package (S. Anderson)

Bending down the VOC curve

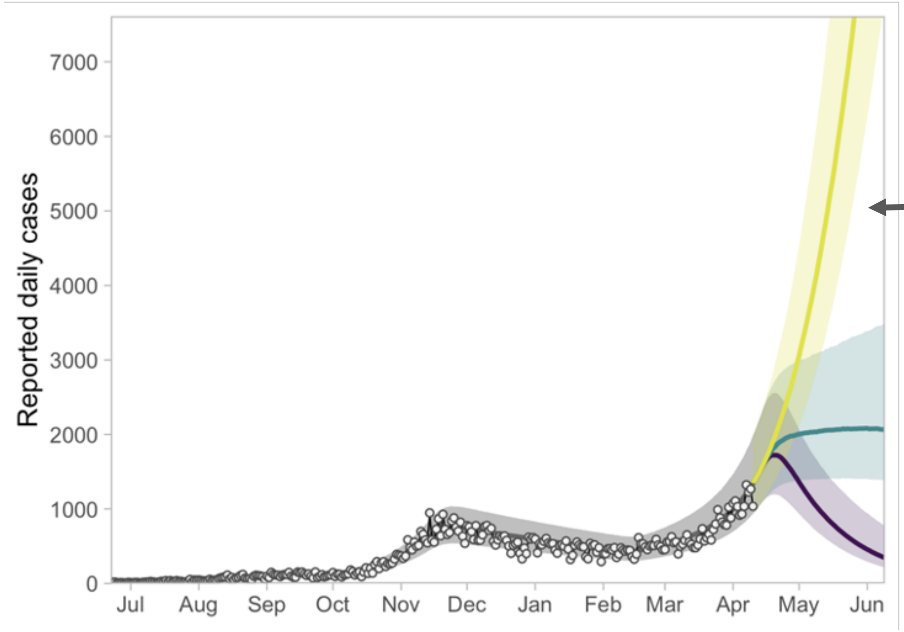


Although too early for a robust statistical measure without more data, estimated VOC case numbers may now be rising more slowly than the exponential growth seen in Feb/March (thick curve).

Thin curves illustrate what we might see if there had been a change in transmission in mid to late March.

Source (S. Otto). Active case numbers from Joint Statements through April 9, 2021 (https://archive.news.gov.bc.ca). VOC data from BCCDC (April 7, 2021) provide % of cases that were VOC by week (see slide 5). These data were fit by a logistic function to estimate percent VOC by day (see Appendix), which was then multiplied by the number of daily cases to estimate the daily number of new VOC cases (red shaded region). Thin red lines are for illustrative purposes only, suggesting what would occur if transmission were reduced by 20-40%, affecting growth in new cases as early as on March 30.

Bending down the VOC curve



How much more do we have to bend down the curve?

These projections show that where we are now is not enough to prevent VOC growth (yellow).

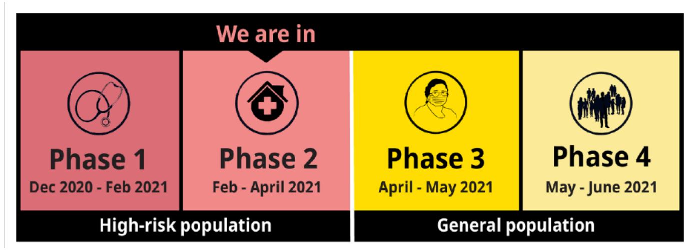
A further reduction in contacts of 20% (blue) to 40% (purple) is needed.

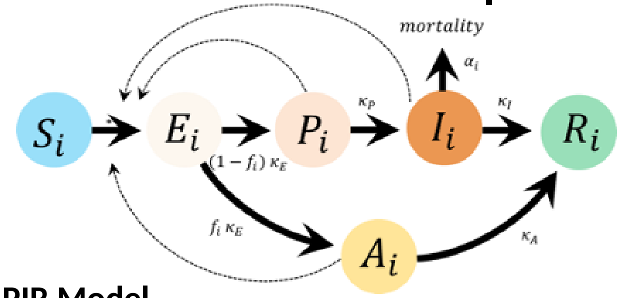
Vaccinating high-contact individuals sooner would help reduce transmission even more (not shown).

Source (E. Are, C. Colijn). Active case numbers projected forward, accounting for VOC data from BCCDC (April 7, 2021). These data provide % of cases that were VOC by week (see slide 5). These data were fit by a logistic function to estimate percent VOC by day (see Appendix). Assuming a 40% increase in transmissibility (consistent with the estimated selection *s* in the Appendix), the percent VOC is used to create an overall reproduction number *R* for the virus population. *R* changes in time as the VOC rises in frequency. The social distancing parameter (among others) is estimated to fit the data using the 'covidseir' R package (version "stan-2.26"; S. Anderson)

Longer-term predictions for VOC depend on vaccination plan

Epidemic model of SARS-CoV-2 using BC data on hospitalization, ICU, and death rates by age and BC's vaccination plan.





SEAPIR Model

S: susceptible

E: exposed

A: asymptomatic (less infectious)

P: pre-symptomatic (infectious)

I: symptomatic (infectious)

R: recovered

10 age classes

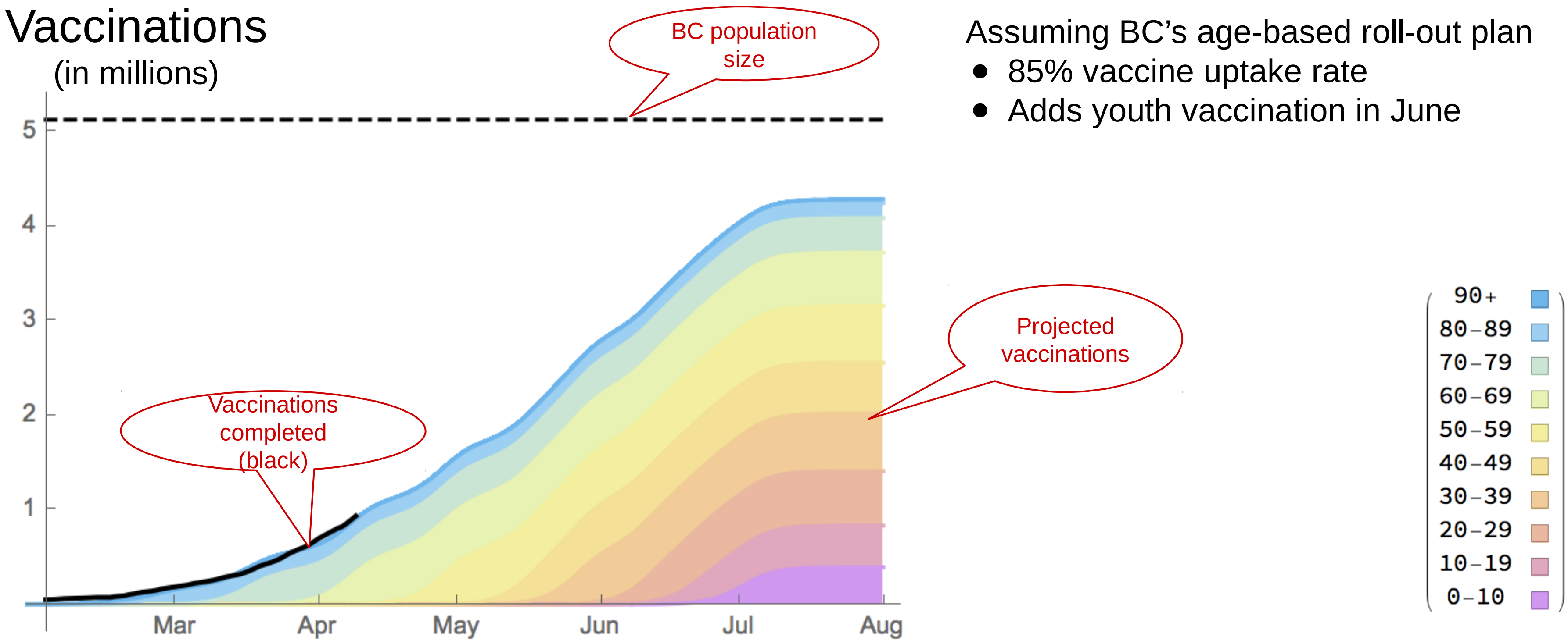
{0-9,10-19,...80-89,90+}

2 distancing classes

- Non-distancing (essential workers)
- Distancing

Source: S. Otto. Based on model in Day et al. (2020)

Longer-term predictions for VOC depend on vaccination plan

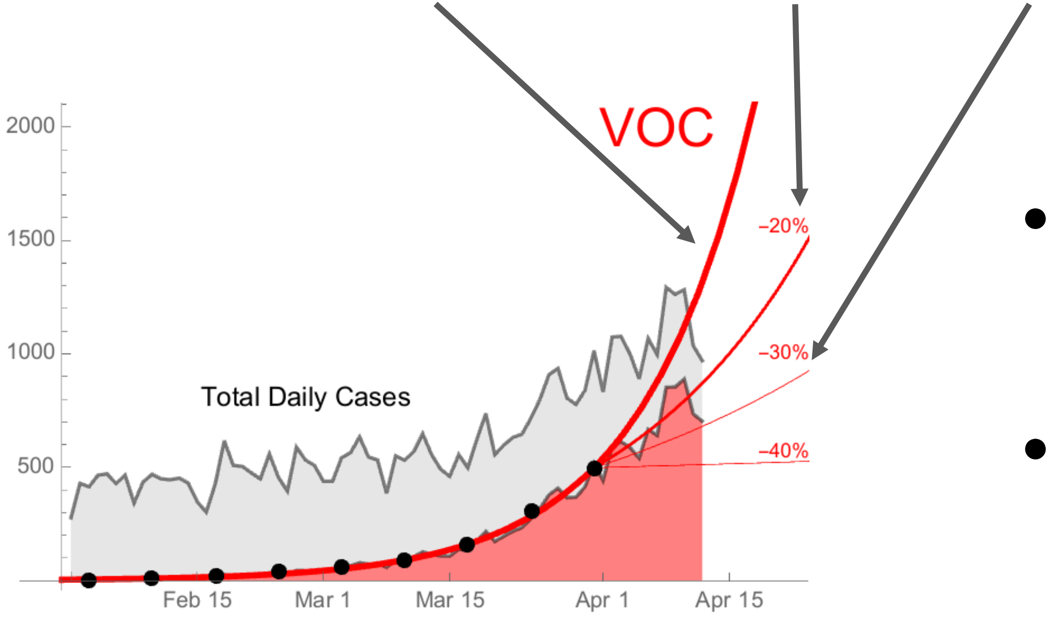


Assuming BC's age-based roll-out plan

- 85% vaccine uptake rate
- Adds youth vaccination in June

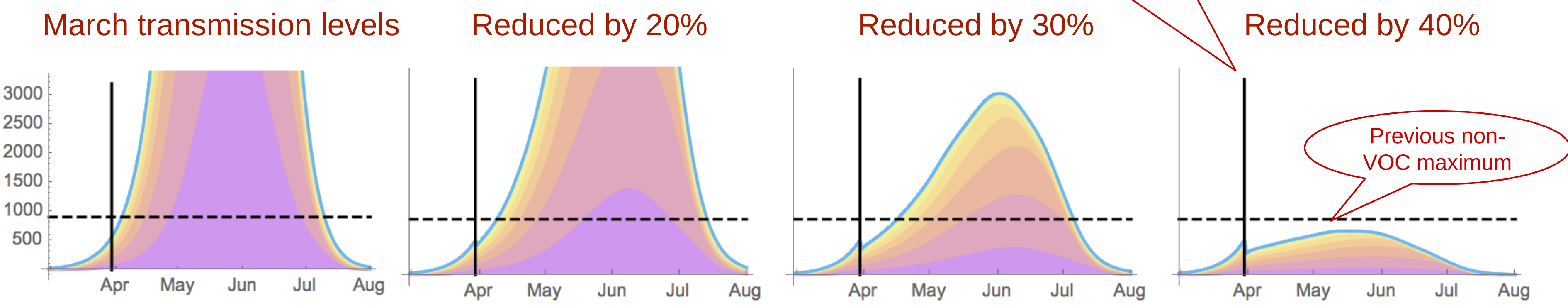
Source (S. Otto). Vaccinations completed from https://health-infobase.canada.ca/covid-19/vaccine-administration/ (87564 subtracted based on second doses before those were paused). 85% uptake rate from PHAC Modelling Group Report (2021-04-08), as found in older age groups (65+) and assuming younger individuals will be encouraged to accept vaccinations more than currently estimated (72% for under age 45).

Longer-term predictions for VOC



- Projections also depend **strongly** on what we collectively do to slow transmission.
- The following slides show a range of transmission levels, reflecting activity and risk levels relative to February/March.

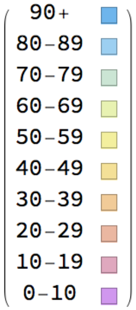
VOC Cases/day



- ➔ **Public health measures and reductions in transmission are needed, alongside the vaccination campaign**
- ➔ **A decline in VOC transmission of 20% relative to February/March will slow but not stop rise in cases.**

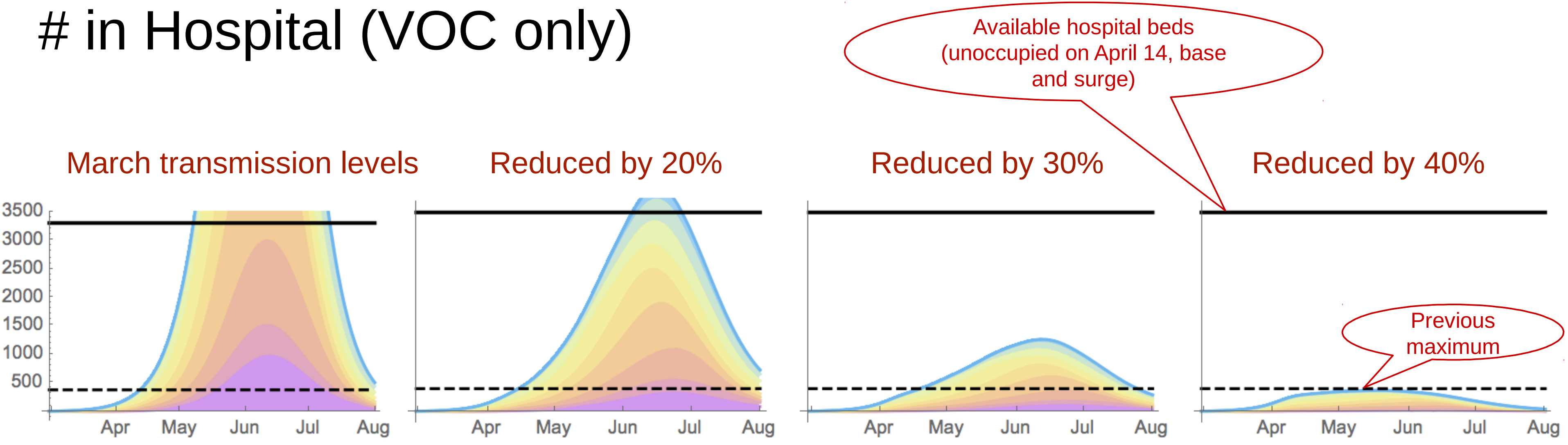
Projections for VOC only:

- Assumes 90% vaccine efficacy and 85% uptake
- 64% higher severity of VOC



Source: S. Otto. Based on model in Day et al. (2020) with age-based vaccination campaign, age-based contact matrix (Mulberry et al. 2020), and two distancing classes as in Anderson et al. (2020). Adjusts transmission to match growth of VOC in March, with total number of active VOC cases as on March 31,

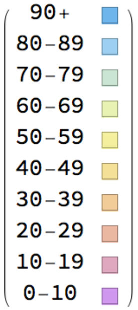
in Hospital (VOC only)



- ➔ **Public health measures and reductions in transmission are needed, alongside the vaccination campaign**
- ➔ **A decline in VOC transmission of 20% relative to February/March will slow but not stop rise in hospital demand.**

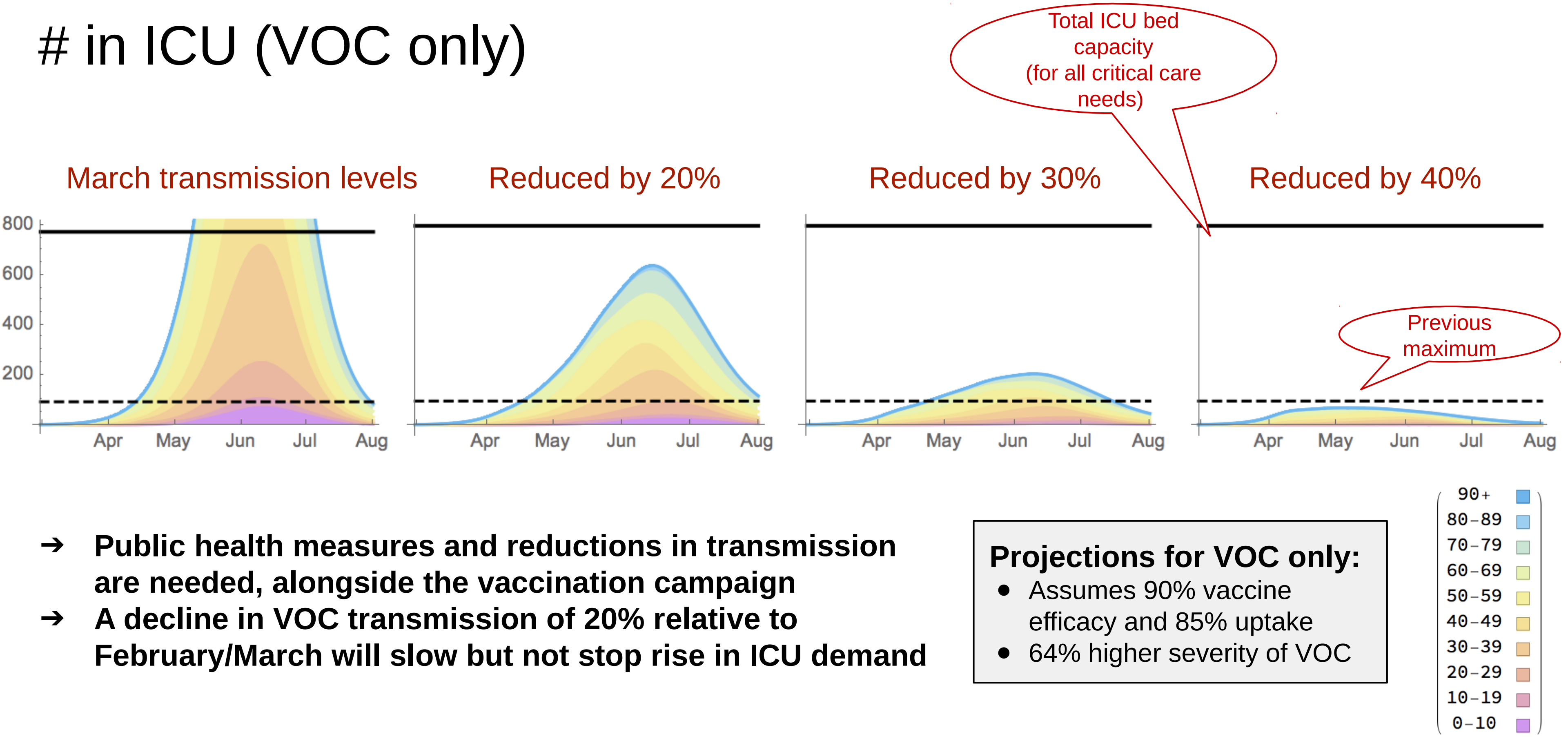
Projections for VOC only:

- Assumes 90% vaccine efficacy and 85% uptake
- 64% higher severity of VOC



Source: S. Otto. Based on model in Day et al. (2020) with age-based vaccination campaign, age-based contact matrix (Mulberry et al. 2021), and two distancing classes as in Anderson et al. (2020). Adjusts transmission to match growth of VOC in March, with total number of active VOC cases as on March 31, 2021. Hospital capacity is available (unoccupied) base and surge beds (Joint Statement, https://news.gov.bc.ca, April 12, 2021); length of stay from CIHI (https://www.cihi.ca/en/covid-19-hospitalization-and-emergency-department-statistics on 10 April, 2021).

in ICU (VOC only)



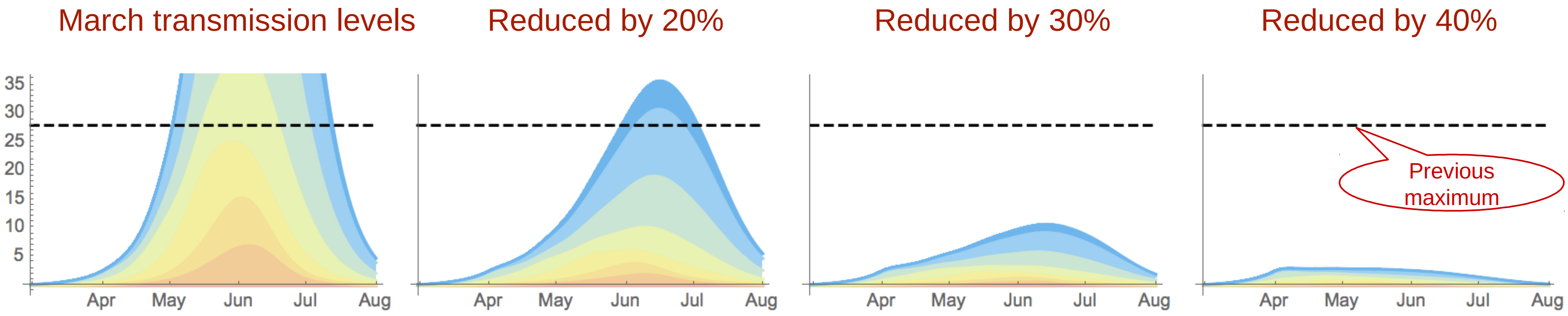
- ➔ **Public health measures and reductions in transmission are needed, alongside the vaccination campaign**
- ➔ **A decline in VOC transmission of 20% relative to February/March will slow but not stop rise in ICU demand**

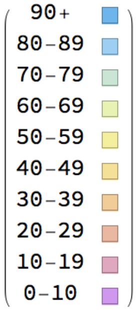
Projections for VOC only:

- Assumes 90% vaccine efficacy and 85% uptake
- 64% higher severity of VOC

Source: S. Otto. Based on model in Day et al. (2020) with age-based vaccination campaign, age-based contact matrix (Mulberry et al. 2021), and two distancing classes as in Anderson et al. (2020). Adjusts transmission to match growth of VOC in March, with total number of active VOC cases as on March 31, 2021. ICU capacity (all beds: base and surge, occupied or unoccupied) from Joint Statement (https://news.gov.bc.ca; April 12, 2021); length of stay from CIHI (https://www.cihi.ca/en/covid-19-hospitalization-and-emergency-department-statistics on 10 April, 2021).

Daily death rates (VOC only)





- ➔ **Public health measures and reductions in transmission are needed, alongside the vaccination campaign**
- ➔ **A decline in VOC transmission of 20% relative to February/March will slow but not stop rise in deaths**

Projections for VOC only:

- Assumes 90% vaccine efficacy and 85% uptake
- 64% higher severity of VOC

Source: S. Otto. Based on model in Day et al. (2020) with age-based vaccination campaign, age-based contact matrix (Mulberry et al. 2021), and two distancing classes as in Anderson et al. (2020). Adjusts transmission to match growth of VOC in March, with total number of active VOC cases as on March 31,

Key messages

- Having reduced transmission of VOCs by 20% relative to February/March bends down the VOC curve but **does not avoid overwhelming hospital capacity**.
- Reducing transmission by 40% relative to February/March is needed to avoid further increases in hospitalization, ICU, and death rates.
- Delays in our collective action allow VOC to rise to higher levels and have more cumulative impact (here assumed effective action taken on March 30).

Caveats

- P.1 and B.1.1.7 assumed to be similar, in the absence of data.
- Projections may worsen if vaccine uptake is less than 85% or effectiveness less than 90%
- Projections may improve by targeting vaccines at transmission hotspots and at essential workers.

Potential mechanisms to reduce VOC transmission:

- ➔ Rapid testing to detect and isolate individuals without symptoms (asymptomatic and presymptomatic cases)
- ➔ Targeting vaccinations to locations and sectors of the population most at risk (reducing transmission)
- ➔ Reduce indoor exposure and increase ventilation (lowering aerosol-based transmission)
- ➔ Identify secondary contacts by rapid testing of primary contacts (before symptoms) and support individuals in their ability to self-isolate

Better data, better inference

- **Expand use of PCR assays to type VOC**
  - to distinguish variants quickly
- **Report:**
  - **VOC typing results daily**
  - **WGS results weekly**
  - **Essential data for reporting**
    - Relevant sample sizes (denominators), sample weeks and VOC strain
    - Nature of sampling design for WGS by week, any large-scale sampling biases (e.g., by region or VOC type), and timelines for WGS.
    - Rationale by which samples were selected for WGS
- **For Vaccinations:**
  - Data broken down by age and location, nature of vaccination: age-based v. essential worker v. hotspot

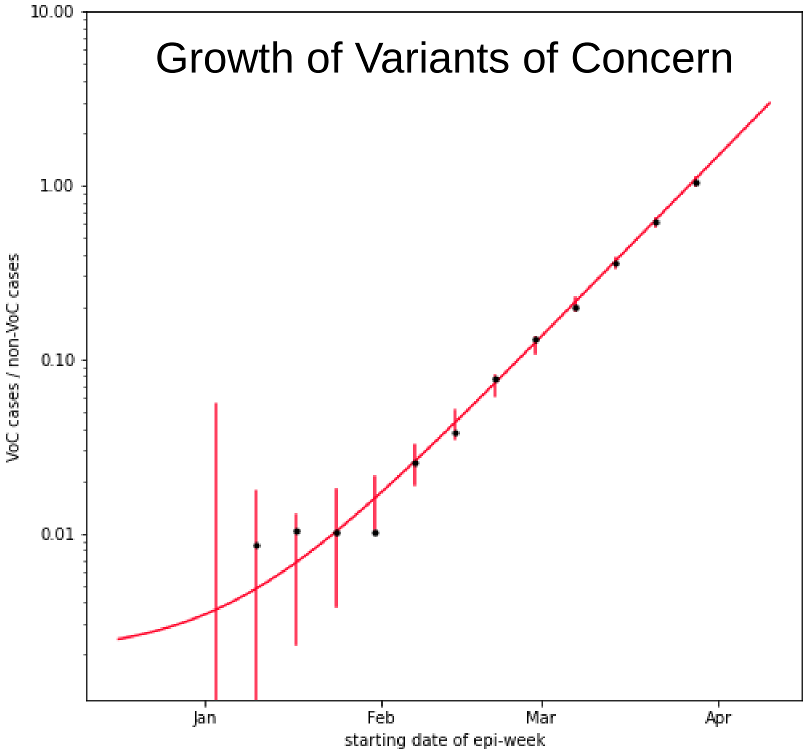
Further messages

- Our models give good projections for the short term
- Preventing overflows in hospitals and ICUs calls for reducing transmission by ~40%, using a combination of efforts (increased mitigation measures, targeted vaccinations, rapid testing, etc.)
- Predictions are limited by data gaps; more accurate models are possible with greater and more timely access to data
- Data access is also important to assess social inequalities in disease incidence and vaccine coverage
- Longer-term projections come with high uncertainty, particularly about our changes in behaviour and any restrictions, but are useful in highlighting what we need to do, in combination with the vaccine roll-out, to curb VOC growth.

Variants of Concern are now dominating the BC epidemic.

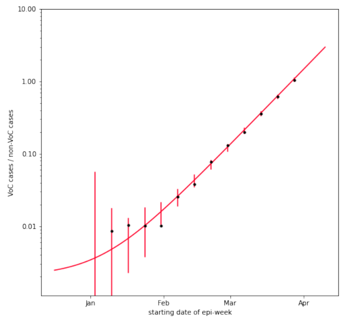
Plot shows ratio of VOC relative to non-VOC (black points), the line of best fit (allowing for false VOC identification, red curve) and 95% central intervals (red vertical bars).

Selection coefficient favouring VOC: s = 0.078 ± 0.002 per day (68% CL)



Source (D. Karlen). VoC data from BCCDC (April 7, 2021). VoC are typed by PCR assays for S:N501Y. Selection coefficient estimated with maximum likelihood (next slide). Estimated date of 75% April 14, 2021 and 95% May 8, 2021. For comparison, Ontario reached 75% on March 31 (https://jamanetwork.com/journals/jama/fullarticle/2778599).

Growth of Variants of Concern



Fit for growth advantage

For an exponential process, the number of cases reported over a period of m days commencing on day d is

$$N(d) = \int_{d}^{d+m} N_0 e^{rt}\, dt = \frac{N_0}{r} e^{rd}(e^{rm} - 1)$$

For two exponential processes (variant and non-variant), the ratio of the daily cases is given by

$$R(d, s, d_0) = \frac{N_v(d)}{N_{nv}(d)} = a \exp(r_v - r_{nv})d = a \exp(sd) = \exp s(d - d_0)$$

where a is a constant, d is an integer day number, and s is the selection coefficient $s = r_v - r_{nv}$. The constant a defines the relative prevalence for the period commencing on day 0. A more suitable parameterization specifies the time d_0 at which the two have equal prevalence.

The fraction of cases that are variant are:

$$f_v(d, s, d_0) = \frac{N_v(d)}{N_{nv}(d) + N_v(d)} = \frac{1}{1 + 1/R(d, s, d_0)}$$

Allow for the possibility that the indicator for VoC (N501Y) has small probability w to mis-identify a VoC. In this case the overall probability for a case to be identified as a variant of concern is

$$p_v(d, s, d_0, w) = (1 - w) * f_v(d, s, d_0) + w$$

Use maximum likelihood to estimate parameters and their covariance. This is a binomial problem, with $n = n_v + n_{nv}$ trials each day and n_v identified as variant.

$$\ln \mathcal{L}(s, d_0, w) = c + \sum_d [n_v(d) \ln p_v(d, s, d_0, w) + n_{nv}(d) \ln(1 - p_v(d, s, d_0, w))]$$

Estimates (68% CL):
s = 0.078 ± 0.002
w = 0.002 ± 0.002