Public Health Agency of Canada

National Microbiology Laboratory

January 14, 2021

COVID-19:

PHAC Modelling Group

Report

Public Health Agency of Canada | Agence de la santé publique du Canada

01 EXECUTIVE SUMMARY AND CONTEXT

EXECUTIVE SUMMARY

The January 14th, 2021 Modelling Report brings together findings of modelling studies conducted by the PHAC Modelling Group with the findings of some additional studies from external modelling partners.

Current situational awareness

The reproduction number (Rt) for Canada on January 2nd, 2021, estimated using date of illness onset, is around 1 (1.04).

- *Rt* is now more consistently > 1 in ON and QC
- *Rt* is < 1 in BC, AB, SK and MB and is below 1 in Atlantic Provinces

The short-range statistical forecast in Canada up to January 21st is:

- 746,9983 cumulative cases (range: 741,389 and 753,882)
- 18,528 cumulative deaths (range 18,270 to 18,774)

Mean case incidence is projected to increase in Canada overall, driven mostly by projected trajectories in Ontario and Saskatchewan. The rate of new deaths is projected to continue increase.

The nowcast of the force of infection suggests that epidemic is increasing in SK, ON, QC and NB. Force of infection is forecast to decline in AB and MB, to remain low in NS and to plateau in BC.

The long-range dynamic modelling forecast in Canada over the next two months includes three scenarios: With current contact rates, the model projects continued resurgence of the epidemic. This is driven by forecasted resurgence in ON and QC, and a possible return to resurgence in BC and SK. With a 20% increase in contact rates, the model predicts a steeper increase in the number of cases over time. With public health measures that result in the equivalent of a 25% reduction in contact rates, the model predicts we can control the epidemic.

Importation risk by modelling for the week of January 3rd to 9th, 2021, estimated that 2064 people with COVID-19 came into Canada, primarily from the US, Mexico, the UK and France.

Assessment of the impact of interventions on the COVID-19 epidemic in Canada and other countries by Oxford University's stringency index:

> In Canada, each of the provinces (for which data are available) are showing recent increases in stringency, after keeping their index below 70 since November. It is too soon to see their effect. Despite the weekly rolling average of daily cases steadily increasing since late December, in Canada public health measures have remained at the same level (64) for almost two months.

- In many countries around the world, trends in cases, deaths and stringency index vary. In many countries, resurgence is occurring, including those where SARS-CoV-2 variants have been detected.

Dynamic modelling

Three dynamic modelling studies explored the impact of vaccination and the new variant of concern (VOC) on the epidemic:

- The study: *Modelling the impact of age-stratified vaccination in the absence of other public health measures*, found that even though all scenarios resulted in reduced clinical cases, hospitalizations, ICU admissions and deaths compared to the baseline scenario, vaccination of older people alone was not sufficient to maintain hospitalizations and ICU admissions below the maximum hospital capacity. The study concludes that, in the absence of non-pharmaceutical public health measures, vaccinating vulnerable age groups alone will not result in bringing severe infections down to a manageable level.

- A study on the *Impact of the new variant strain and the speed and coverage of vaccination in the Canadian population* showed that a more transmissible strain of SARS-CoV-2 will result in the epidemic being harder to control, at our current rate of vaccination. It concludes we will need to increase vaccination efforts significantly to see the impact of the vaccine on the epidemic. Even with regular shutdowns, vaccination will only reduce the epidemic minimally unless other public health interventions are enhanced.

  The study: *Theoretical scenario projections for SARS-CoV-2 variant of concern (VOC) B.1.1.7 introduction into provinces in Canada* developed long term projections of reported cases for major provinces, using different proportions of the population infected initially with the VOC. The projections suggest that with an expansion of the VOC in all major provinces, the epidemic could accelerate markedly unless there is an increase in public health measures.

- The study on: *The impact of the emergence of the UK COVID-19 strain B 1.1.7 (VOc-202012/01), and waning immunity on the current epidemic in Canada* predicts that waning immunity will not play a significant role in how the epidemic will unfold in the short term compared with the speed of the emergence of a new, more transmissible variant. This VOC could provoke a dramatic increase in the total final attack rate as well as increase the size of a possible third wave in late summer 2021.

Special report

The special report: a *Note on the analysis of COVID-19 testing data* shows that changes in numbers of positive test results, and positivity rates, are influenced by the proportion of the population that is tested and the sampled population. Consequently, policy statements and decisions should not be based upon a single measure, such as the positivity rate, without taking into account other measures and factors such as policies for testing, the probability of being tested, the target population for testing, and how these may change over time.

CONTEXT

COVID-19 has spread across the world, and the associated morbidity and mortality, spawning extensive international research to inform both clinical and public health evidence-based actions to mitigate its effects.

The COVID-19 PHAC Modelling Group prepares this publication every two weeks. The objective is to share the results of this Group on domestic situational awareness, international situational awareness, on dynamic modelling studies looking at the COVID 19 epidemic and public health measures and any Special Reports that may arise from the Modelling Group or our external partners. The Annexes identify the list of contributors, some foundational work, such as the PHAC scenarios for the COVID-19 epidemic in Canada for planning Autumn/Winter 2020-2021 and more in-depth information on the methodologies of the summarized studies.

It is important to note the limitations of modelling studies. They rely on estimates that may be derived from other countries and therefore there is inherent uncertainty when extrapolating this to Canada. And the data from Canada and globally are constantly evolving. As a result, there may be a lag time before estimates in the model and its outputs are able to reflect this.

02 DOMESTIC SITUATIONAL AWARENESS

REPRODUCTIVE NUMBER FOR CANADA

Key points

- National Rt based on data of onset from end of August to December was mostly >1 indicating that nationally the epidemic continues to expand.
- Rt is consistently > 1 in ON and QC.
- Rt is < 1 in BC, AB, SK and MB suggesting that public health measures and/or public response were impacting the epidemic

Background

The effective reproduction number (*Rt*) represents the average number of people that one infected person can infect and the rate at which a disease spreads within a population at a specific point in time. This measure provides information on the impact of any public health measures in place.

Method

The effective reproduction number *Rt* is calculated using the R package EpiEstim (version 2.2-3). The daily number of reported cases is used as a proxy for daily incidence. The most recent data of reported cases are updated several days after their initial reporting. Hence, to avoid adding potentially misleading noise in the estimation of *Rt*, only data at least 11 days old are taken into account

Results

National *Rt* based on data of onset from end of August to the end of December was mostly >1 indicating that nationally the epidemic continues to expand. *Rt* declined from end of September to early October but now fluctuates around 1 (at 1.04 on January 2nd). *Rt* is now more consistently > 1 in ON and QC. Rt is < 1 in BC, AB, SK

and MB suggesting that public health measures and/or public response may be impacting the epidemic at this snapshot. Rt is at or below 1 in the Atlantic Provinces (not shown).

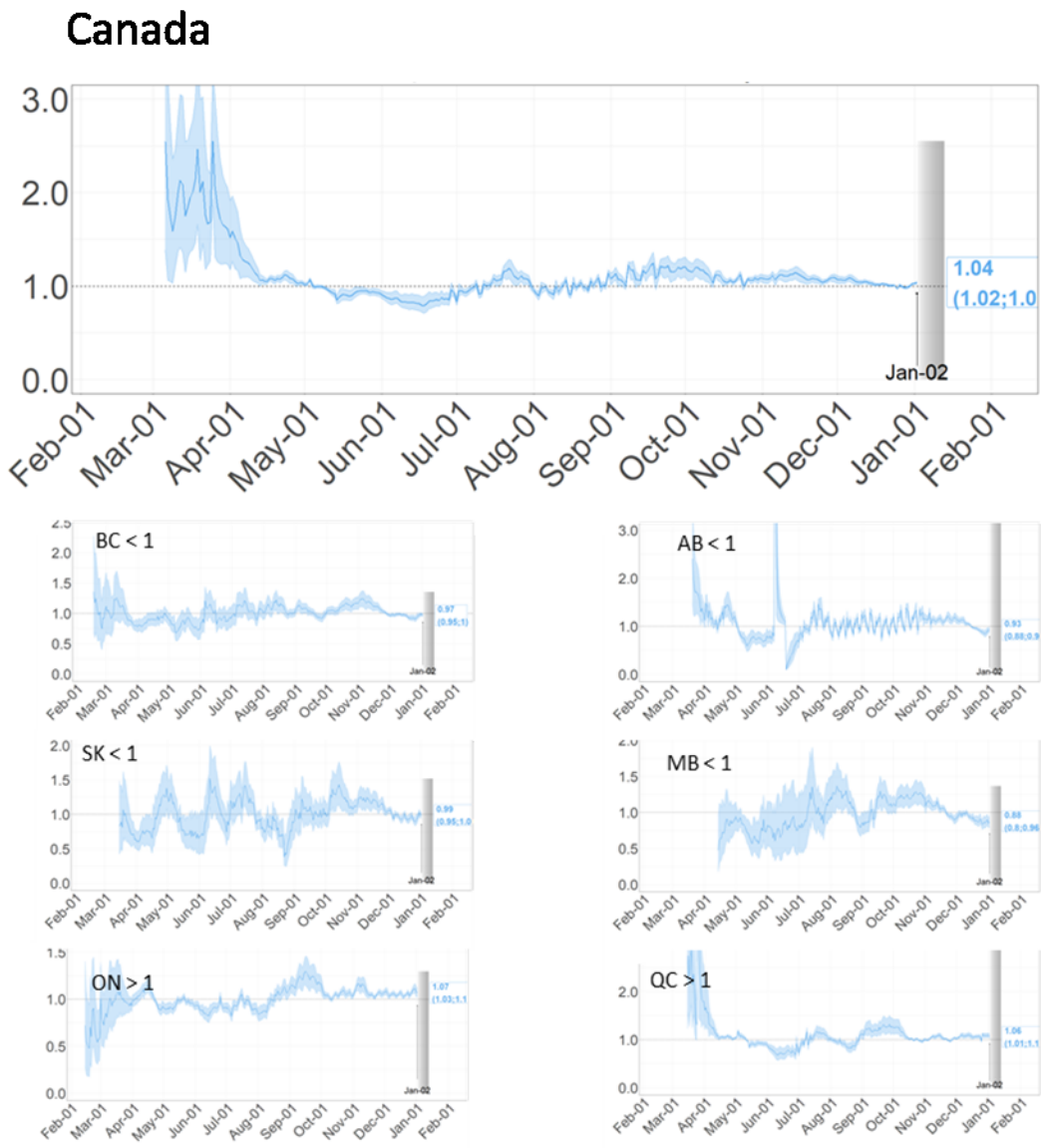


Figure 1. *Rt* estimates (with 95% confidence intervals) for Canada as a whole and individual provinces, from mid-February 2020 to January 2nd 2021.

SHORT RANGE FORECAST OF REPORTED CASES AND DEATHS IN CANADA BY THE GENERALIZED RICHARDS MODEL (GRM)

Key Points

- The number of cases reported on January 21st is projected to reach between 741,389 and 753,882 (mean = 746,983).
- Reported deaths are projected to range from 18,270 to 18,774 (mean = 18,528) by the end of January 21st.

Background

Phenomenological modelling approaches are used to project future cases in Canada in the near term. Future growth of the pandemic in Canada is based entirely on historic reported case counts (from https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection.html), and the models do not explicitly consider the mechanisms of transmission of COVID-19, including human behaviours and response to the pandemic (social distancing, facility closures and openings, etc). The models also do not account for any delays in testing, testing backlogs, changes to number of tests performed daily, changes to testing eligibility, etc. Nevertheless, they can provide estimates of the trajectory of reported cases, and can be retroactively examined to identify apparent changes in trajectory.

Method

The Generalized Richards Model (GRM) (see Annex for more description) was fit to Canadian case and death data up to and including December 15th. Case and death projections were produced for Canada as a whole, and case projections were produced only for provinces with sufficient reported cases over the past several weeks. The grey shaded area indicates data reported prior to the projection date.

Projections produced for the last report (using data through December 1st) are plotted alongside case and death data reported since that time to retroactively examine model performance. The coefficient of determination (R^2) values are provided for an indication of model fit to cases and deaths reported in Canada from the weeklong period since the projection date.

Results

Mean case incidence is projected to increase in Canada overall, driven mostly by projected trajectories in Ontario and Saskatchewan. The rate of new deaths is projected to continue increase.

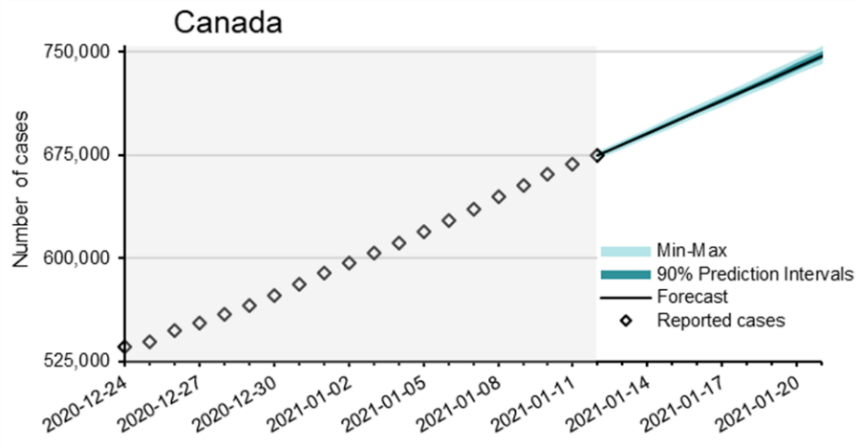


Figure 1. Short range forecast for reported cases in Canada.

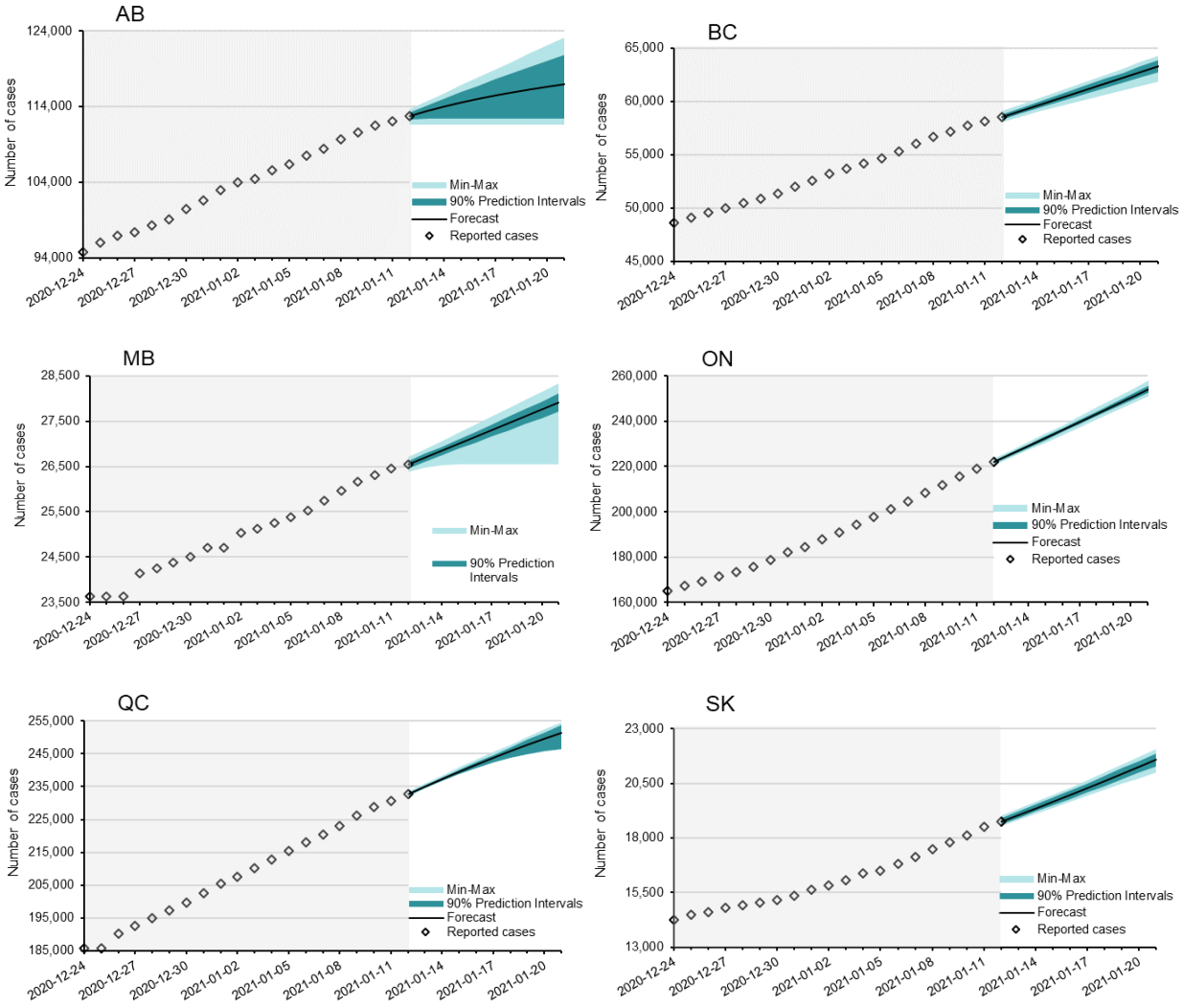


Figure 2. Short range forecast for reported cases in provinces with sufficient data.

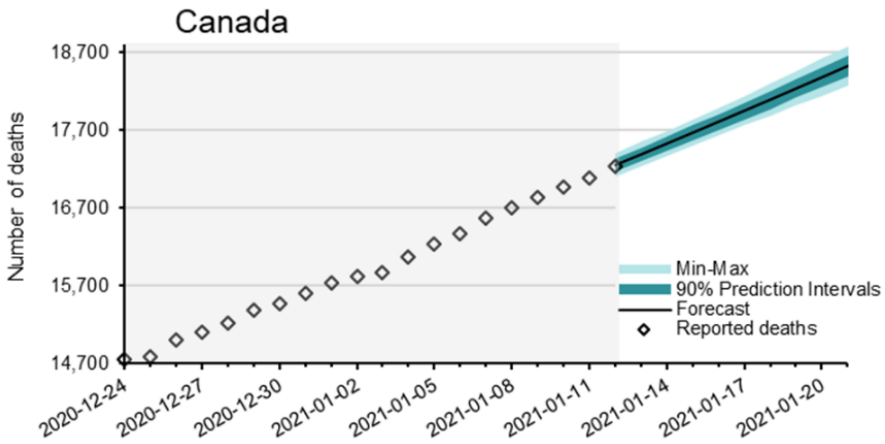
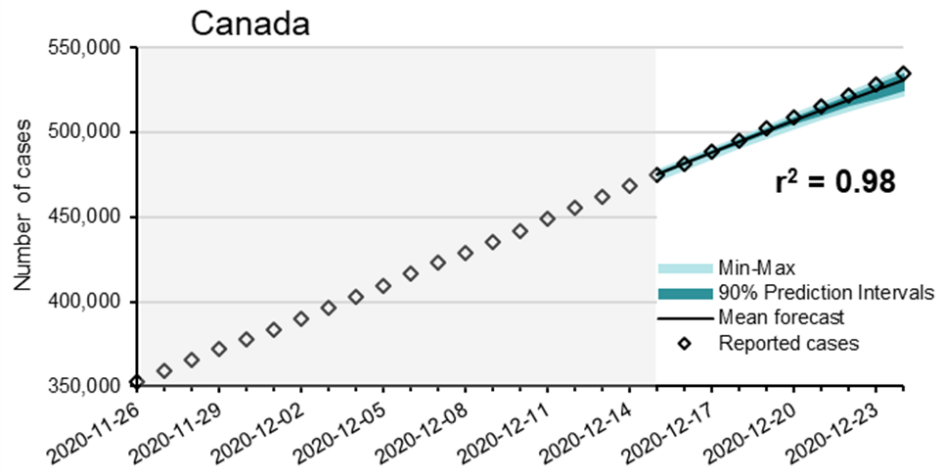
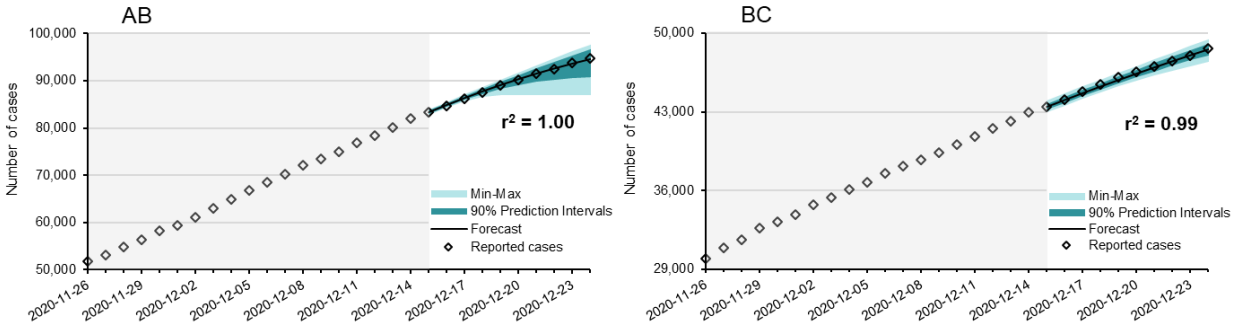


Figure 3. Short range forecast for reported deaths in Canada.

The mean projection of the GRM included in the last modelling report under-predicted the reported case counts on December 22nd by 0.47% (2,461 cases). Visual examination of model performance for each provincial projection included in the last report indicates that the trajectory of the pandemic improved in Manitoba and Saskatchewan, and worsened in Ontario and Quebec, compared to the GRM projection.





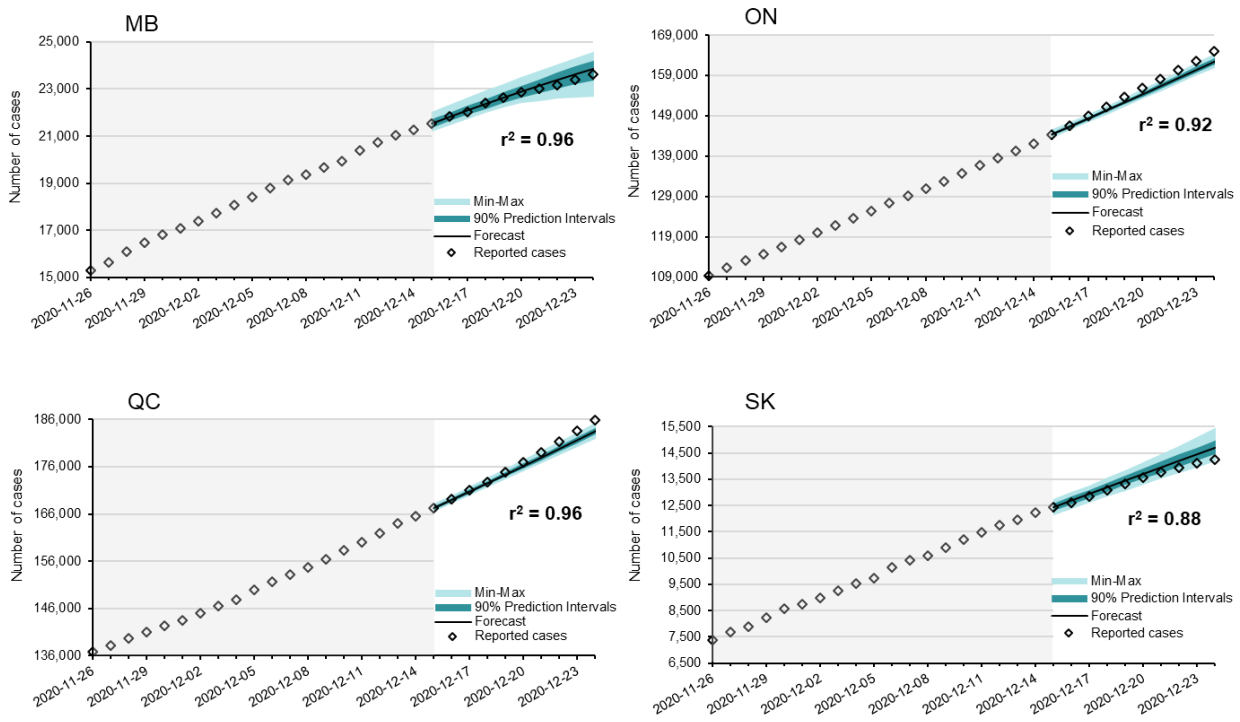


Figure 4. Performance of short range case forecasts produced for the last modelling report.

The projection mean included in the last modelling report under-predicted actual deaths reported on December 22nd by 0.22% (32 deaths).

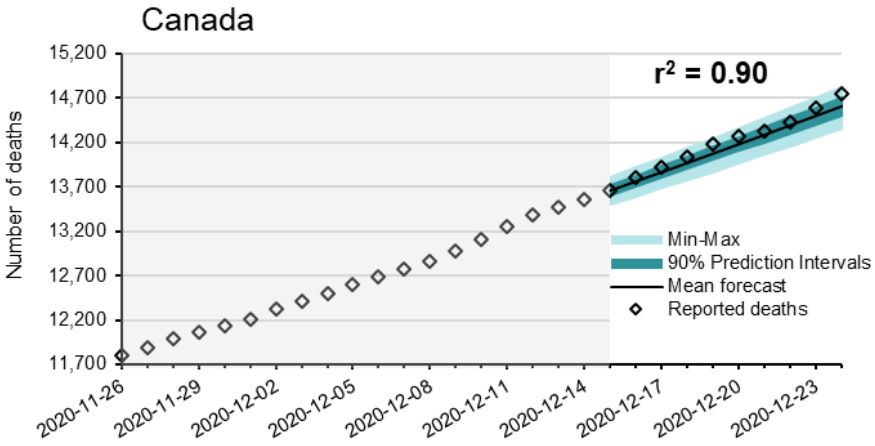


Figure 5. Performance of the short range death forecast for Canada produced for the last modelling report.

NOWCASTING THE FORCE OF INFECTION

Key Points

- Force of infection is increasing SK, ON, QC and NB.
- Force of infection is forecast to decline in AB and MB, remain low in NS and plateau in BC..

Background

Data on cases, hospitalisations, ICU, deaths and testing are used to more accurately nowcast the status of the epidemic using the force of infection. The force of infection represents the per day risk of infection for a susceptible person circulating in the community. These outputs are provided by Dr Nathaniel Osgood and his team, University of Saskatchewan.

Method

The methods to produce these estimates include the Bayesian Sequential Monte Carlo method of particle filtering, but may also include support by Particle Markov Chain Monte Carlo techniques. This methods allow for a model that learns as new data becomes available, by recurrently regrounding estimates of the current system state in the model against observed data. (Reference: Safarishahrbijari A, Teyhouee A, Waldner C, Liu J, Osgood ND. Predictive accuracy of particle filtering in dynamic models supporting outbreak projections. BMC Infect Dis. 2017 7(1):648).

Results

The graphics represent the force of infections from February to the present.

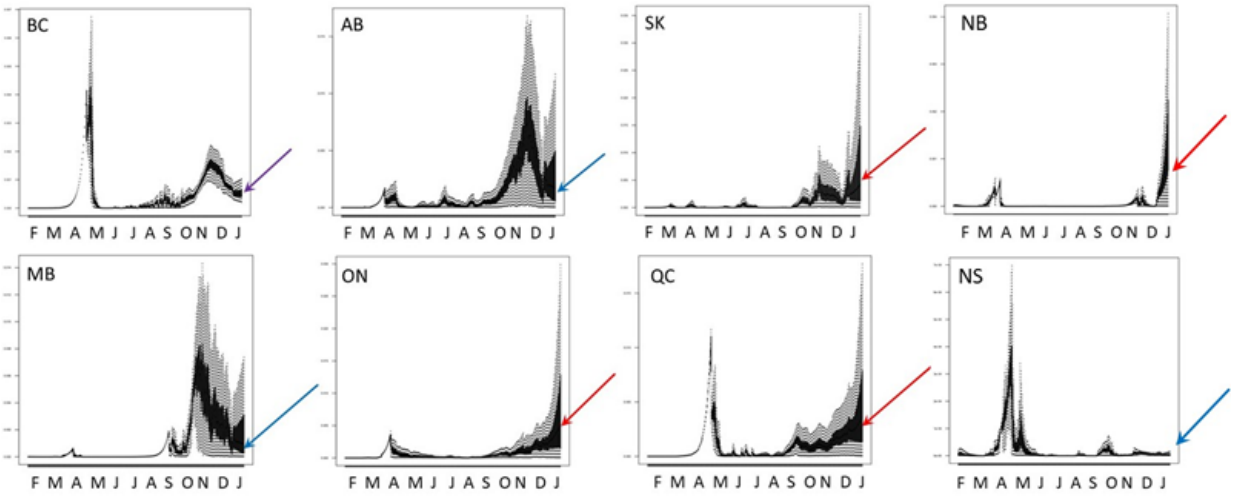


Figure 1. Values for the force of infection (the daily rate at which susceptible people acquire infection) from February to the present (black points) with lower and upper quartiles (darker stipple), and minimum and maximum values (lighter stipple). Red arrows indicate increasing, blue arrows decreasing, and mauve arrows constant force of infection.

LONG RANGE FORECAST OF REPORTED CASES IN CANADA USING DYNAMIC MODELLING

Key Points

- The long range forecast suggests that, overall for Canada, the trajectory is for resurgence of the epidemic over the coming two months with ~10,000 daily cases by end of January.
- In a model scenario, 25% reduction in contact rates (as a proxy for increased control measures) may help bring the epidemic under control.
- To achieve the equivalent of a 25% reduction in contact rates, re-implementation of some restrictive closures will be required.

Background

A dynamic model is used to produce a forecast of reported cases over the next two months. The forecast is based on current estimates and does not anticipate future changes (e.g. opening schools, widening testing). This analysis is a courtesy of Dr. Caroline Colijn and Team, Simon Fraser University.

Methods

The long-range modelling and forecasting approach uses a dynamic SEIR-type model with Province-specific parameters fit with Bayesian methods, in particular the degree to which implementation and lifting of restrictive closures impact contact rates, while accounting for other public health measures (case detection and isolation, and tracing and quarantine of contacts) as far as is possible. Details of the methods can be found at: https://www.medrxiv.org/content/10.1101/2020.04.17.20070086v1.

Results

The long range forecast suggests that, overall for Canada, the trajectory is for continuing resurgence of the epidemic over the coming months. This is driven by forecast resurgence in ON and QC, and a possible return to resurgence in BC and SK. Increasing contact rates by further re-opening would increase the speed of resurgence, and at current rates >25% reduction in contact rates (as a proxy for increased control measures) may help bring the epidemic under control. This is not meant to imply that each Canadian should reduce their own contact rates by 25%, this reduction in contact rates will require re-implementation of some restrictive closures. Enhancements to other public health measures (testing and tracing) would likely also help bring the epidemic under control but are not modelled here.

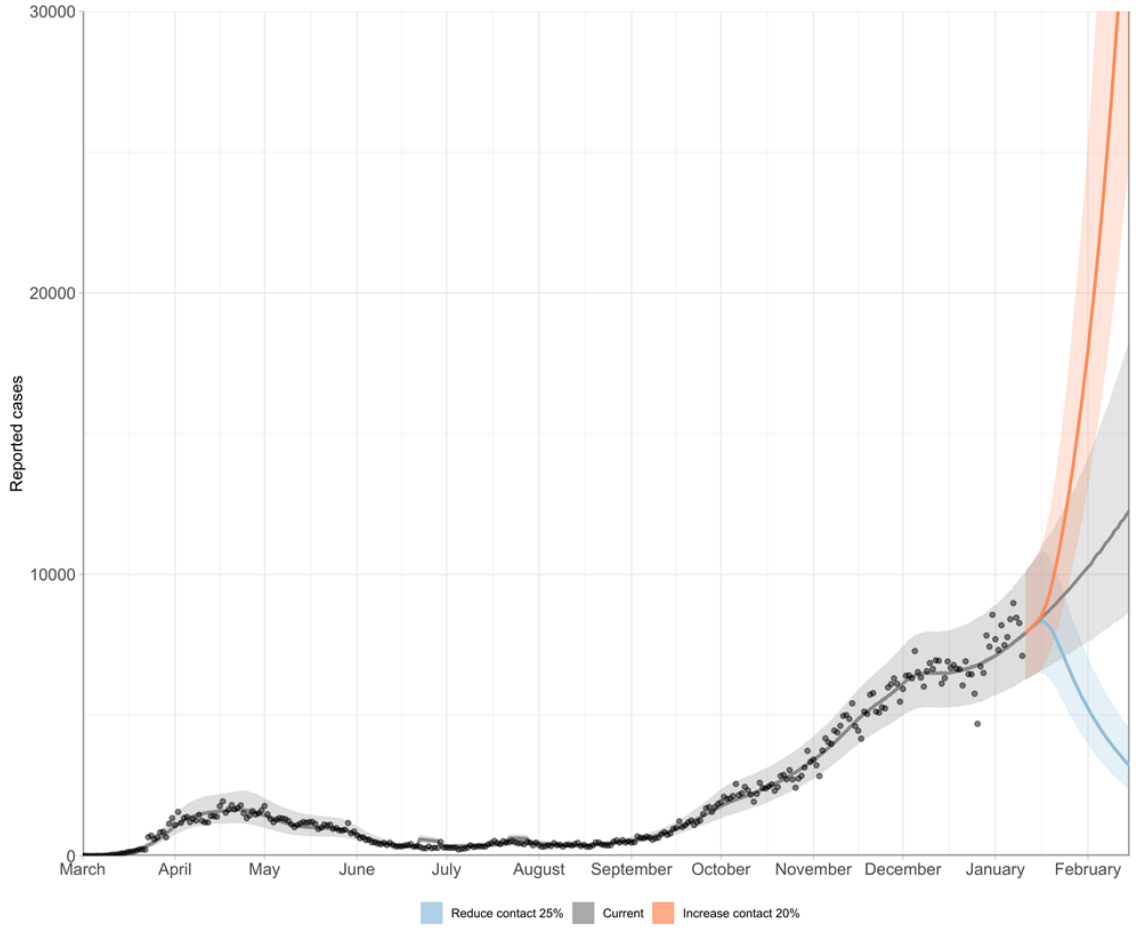


Figure 1. A projected incidence for the next 2 months (gray line). The orange line forecasts cases with 20% increased contact rates, while the blue line forecasts cases with 25% decreased contact rates. Shaded areas show 90% credibility intervals.

03 INTERNATIONAL SITUATIONAL AWARENESS

IMPORTATION RISK BY AIR AND LAND

Key Points

- Highest importation risk continues to be from the US.
- Order of highest risk airports: Toronto Pearson, Montréal-Trudeau International, Vancouver International, Calgary International, Edmonton International, Ottawa International, Winnipeg International, Halifax Stansted International.

Background

The importation risk model provide importation information on the risk associated with travel within Canada and from other countries. This model estimates the mean number of air travelers infected with COVID-19 arriving weekly to Canadian ports of entry (PoEs), by combining data on spread of COVID-19 through air and land travel, country-specific weekly incidence rate, and temporal infection dynamics.

Methods

The importation risk model estimates the mean number of travelers infected with COVID-19 arriving weekly to Canadian air and land ports of entry (PoEs). The estimate is a function of exposure probabilities to COVID-19 given time spent since the start of the pandemic in the country of residence (for Canadian residents, CR and foreign nationals, FN), and for CRs, the estimate also accounts for exposure in the country visited before returning to Canada. Travel volumes are for air and land travel, the latter being for US departures only. The role of domestic travel to contribute to infected travellers at air PoEs is not considered.

The model accounts for underreporting in national surveillance systems at the country level (see Model Structure for details). Symptomatic people are not allowed to travel, but also, some people that become symptomatic will travel during their incubation period when no symptoms are presenting. Therefore, the estimates of infected travellers are for people that are assumed to be asymptomatic or in their incubation period. Results shown for this week are for January 3rd to 9th. A future version of the model will account for travel restrictions given the policy announced by the GoC on January 7th 2021 that travellers cannot fly to Canada unless having received a negative test result 1-3 days before departure.

Results

National level by air and land

There were 2064.6 (± SD 17.5) infected travellers expected from 141 countries for the week January 3rd to 9th.

National level by air travel only

The USA continues to be the main source of importation risk to Canada, followed by Mexico/UK and France.

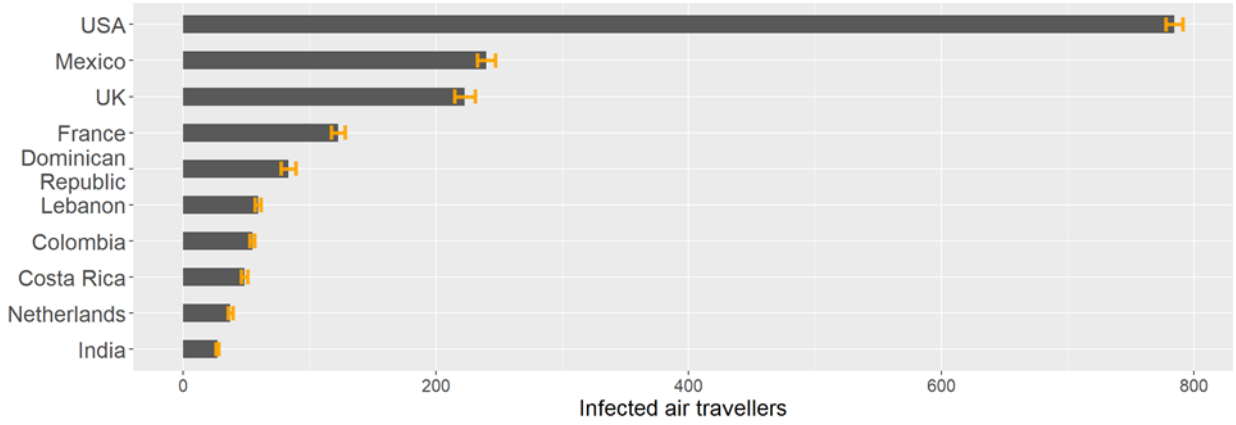


Figure 1. Top 10 countries expected to have contributed infected travellers to Canada for Jan. 3rd to 9th.

Regional level by air travel

The countries contributing infected travellers vary at the regional level for the major Canadian airports.

Table 2. The mean and standard deviation of the number of infected travellers arriving at major Canadian airports. Also shown are the number of countries contributing infected travellers and the top countries.

Airport	Mean Number of infected travellers (SD)	Number of contributing counties	Top countries
Toronto Pearson	859 (± SD 13)	134	USA, Mexico, UK
Montréal-Trudeau International	432 (± SD 9)	126	USA, France, Dominican Republic, Mexico
Vancouver International	277 (± SD 5)	108	USA, UK, France, Mexico
Calgary International	197 (± SD 3)	97	USA, UK, Mexico
Edmonton International	63 (± SD 1)	90	USA, Mexico, UK
Ottawa International	50 (± SD 1)	87	USA, Lebanon, UK
Winnipeg International	28 (± SD 0)	67	USA, UK, Mexico
Halifax Stansted International	22 (± SD 0)	60	USA, UK, France

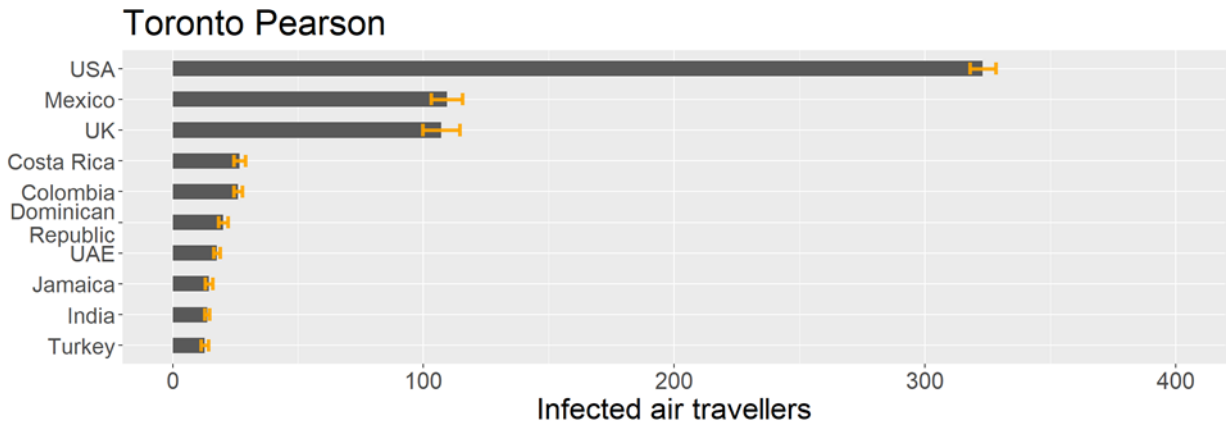


Figure 2. Top 10 countries expected to have contributed infected air travellers to Toronto Pearson Airport for Jan. 3rd to 9th.

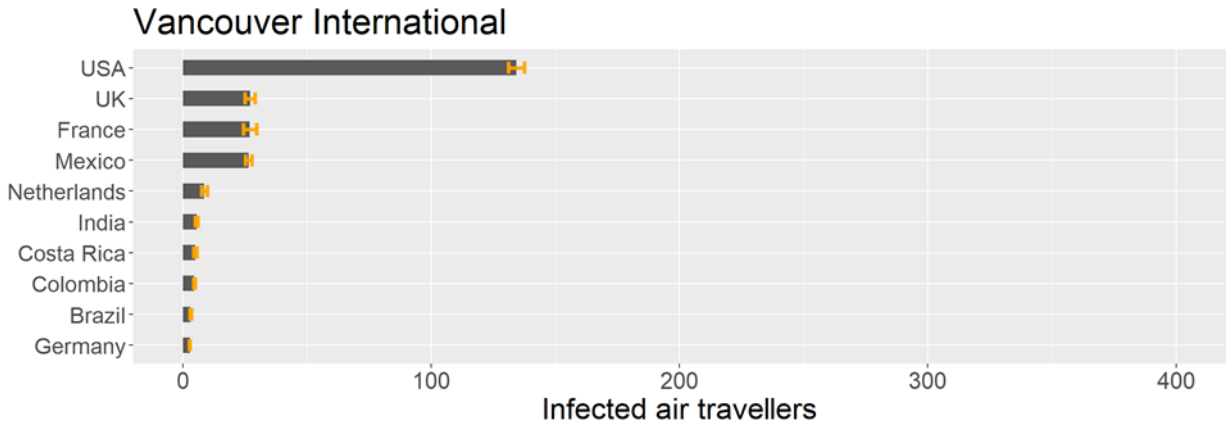


Figure 3. Top 10 countries expected to have contributed infected air travellers to Vancouver International Airport for Jan. 3rd to 9th.

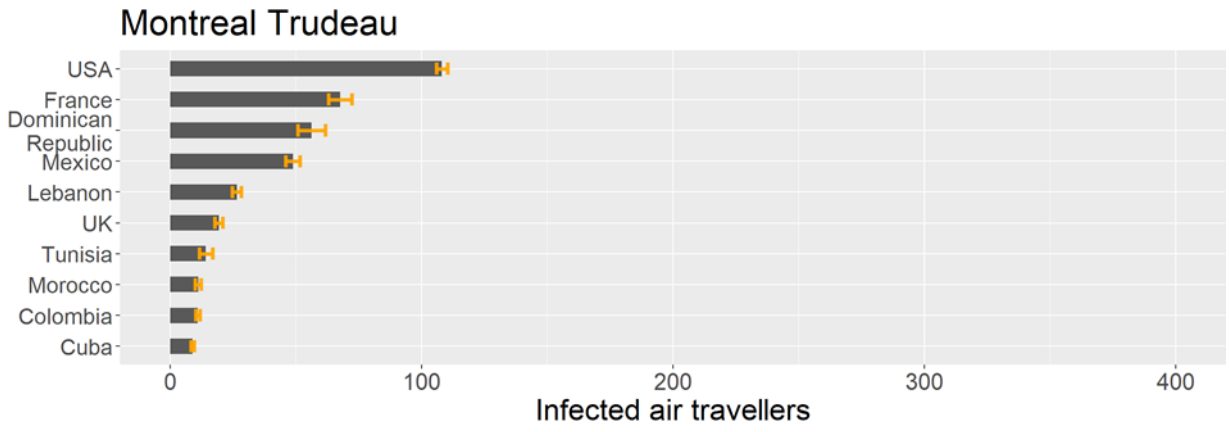


Fig. 4. Top 10 countries expected to have contributed infected air travellers to Montreal-Trudeau International Airport for Jan. 3rd to 9th.

Provincial level by land travel

The mean number of infected travellers predicted to arrive at land PoEs from the USA is highest for Ontario (Table 3).

Table 3. The mean and standard deviation of the number of infected travellers arriving in Canada at land PoEs from the USA, as summarized by province, for the week of Jan. 3rd to 9th.

Province	Estimated mean infected travellers	Standard deviation
Ontario	2609.9	84.6
British Columbia	805.4	30.7
Quebec	388.8	15.1
New Brunswick	165	4.3
Manitoba	160.5	9.1
Alberta	90.1	6.4
Saskatchewan	70.1	4.1
Yukon	5.3	0.5
Newfoundland and Labrador	0.8	0.1
Prince Edward Island	0	0

COMPARING CANADA WITH OTHER COUNTRIES BY PUBLIC HEALTH MEASURES

Key Points

- Despite the weekly rolling average of daily cases steadily increasing since late December, 2020 to over 8200 cases on Jan. 10th, 2021, Canada has kept their public health measures at the same level for almost two months (stringency index has remained at 64 since Nov. 18, 2020).
- Resurgence of the epidemic is occurring in many countries around the world including those with newly identified SARS-CoV-2 variants. Trends in cases, deaths and stringency index vary in some countries where SARS-CoV-2 variants have been detected.
- Generally, stringency indices for multiple Canadian provinces and territories have increased over the last month or longer. However, in some cases, a recent decrease in the stringency index has occurred despite an increase in cases and this may not be sufficient to bring the epidemic under control.

Background

The stringency index is a semi-quantitative combination of information from nine different public health interventions: school closing, workplace closing, cancelling public events, restrictions on gathering size, closing public transport, stay at home requirements, restrictions on internal movement, restrictions on international travel, and public information campaigns. This index is mapped with Covid-19 disease outcome data from other countries to flag interventions that could be having an effect. The figures in this report show the current epidemiological situation, in Canada and selected other countries, alongside the level of stringency index (termed "Government Response" in figures).

Methods

International: Covid-19 surveillance data are from the Johns Hopkins University (JHU) Coronavirus Resource Centre https://coronavirus.jhu.edu/map.html and are mapped with public health intervention data from the Government Response Tracker (University of Oxford - https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker).

Previously, Covid-19 data were from the European Centre for Disease Prevention and Control (up to December, 14, 2020) but changes in reporting frequency and format necessitated a switch to JHU in January, 2021 for all disease data except for Canada.

Provincial/territorial: Covid-19 surveillance data are from the same source as above and public health intervention data are from Health Canada (HC FPT Intelligence) and from additional data mining and coding of publicly-available information by the Public Health Agency of Canada.

The main purpose of combining these two sources of information is to flag interventions that could be having an effect. The dashboard views in this report show how the epidemiological situation in Canada, and selected

countries, and the stringency index has changed over time. The stringency index is a measure of the level of interventions, and where available, details of the interventions are provided.

Results

a) **National:** As of January 11, 2021, Canada had a stringency index of 64 according to Oxford data at the national-level[1]) despite the significant increase in cases during this second wave (Figure 1). This level of stringency has been the same since Nov. 18/2020 (almost two months). The weekly rolling average of daily cases has been steadily increasing since late December 2020 and was >8200 cases on January 10th, 2021. The weekly rolling average of daily cases on January 12, 2021 was 7943 cases or 21.1 cases/ 100,000 (Figure 1). The weekly rolling average of daily deaths on January 12, 2021 was 143 deaths or 0.38 deaths/ 100,000 (Figure 2).

b) **International:** The countries included in Figure 1 and Figure 2 below were selected as they represent examples where various SARS-CoV-2 variants of concern have been detected.

Ireland: Dramatic resurgence of the epidemic is occurring in Ireland as part of a 3rd wave of cases since mid-late December, 2020 as shown in Figure 1. As of January 12/21, the weekly rolling average of daily cases in Ireland is 122.3 cases/100,000 (ranked 1st worldwide). The stringency index in Ireland was increased to 81 preceding the 2020 holiday season for just over a month (i.e. October 21-December 3) then decreased to as low as 69 on December 24th. As cases began to rise dramatically, the stringency index was increased to 88 for one week (January 1-8, 2021), then decreased to the current value of 85 (Figure 1). Despite the dramatic increases in cases in Ireland, the weekly rolling average of daily deaths per 100,000 has remained relatively low and stable (46th worldwide); this observation appears to be unique to Ireland when compared against the other countries shown in Figure 2. That said, recent data are showing a slight increase in average daily deaths in Ireland (Figure 2).

Germany: Resurgence of the epidemic in Germany has generally been sustained at a weekly rolling average of daily cases of >20 cases/100,000 since early November 2020. On January 12, 2021, the weekly rolling average of daily cases was 26.2 cases/100,000 (29th worldwide). From mid-October to mid-December 2020, the stringency index ranged from 59-68 followed by an increase to the current value of 85 (Figure 1). The weekly rolling average of daily deaths per 100,000 in Germany has steadily increased during this period of resurgence to the highest levels seen to-date in that country (1.05 deaths/100,000 on January 12, 2021; ranked 10th worldwide) (Figure 2).

United Kingdom: Resurgence of the epidemic in the United Kingdom continues with the weekly rolling average of daily cases at 16.9 cases/100,000 on January 12, 2021 (51st worldwide). In recent days, there has been a slight decrease in the weekly rolling average of daily cases. The stringency index in the UK has fluctuated between 64 in early December, 2020 to its current value of 75 which has been in place since January 5, 2021 (Figure 1). The weekly rolling average of daily deaths per 100,000 in the UK has steadily increased during resurgence to the highest levels seen to-date in that country (0.30 deaths/100,000 on January 12, 2021; ranked 51st worldwide) (Figure 2).

South Africa: Resurgence of the epidemic in the South Africa continues with the weekly rolling average of daily cases at 31.8 cases/100,000 on January 12, 2021 (23rd worldwide). Following the first wave, the stringency index in South Africa was decreased for a substantial period of time (late September, 2020 to January 3, 2021) to values ranging from 36-47. On January 4, 2021, the stringency index was increased to 64

[1] Note: data on Canadian national public health measures were last updated on January 11th, 2021.

where it currently sits (Figure 1). The weekly rolling average of daily deaths per 100,000 in South Africa has continued to increase during resurgence to the highest levels seen to-date in that country (0.92 deaths/100,000 on January 12, 2021; ranked 13th worldwide) (Figure 2).

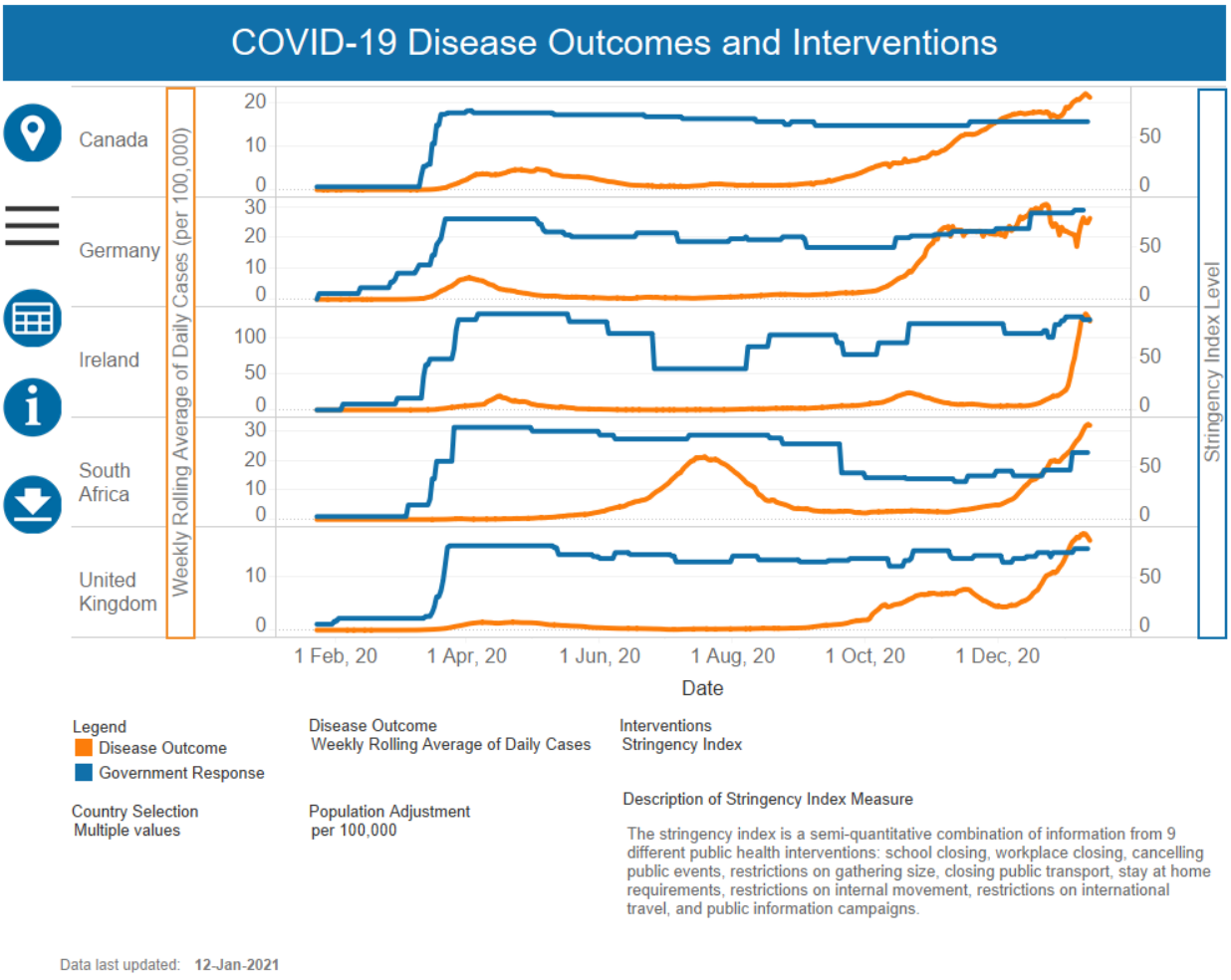


Figure 1. Canada and selected other countries; weekly rolling average of daily cases of Covid-19 per 100,000 and interventions.

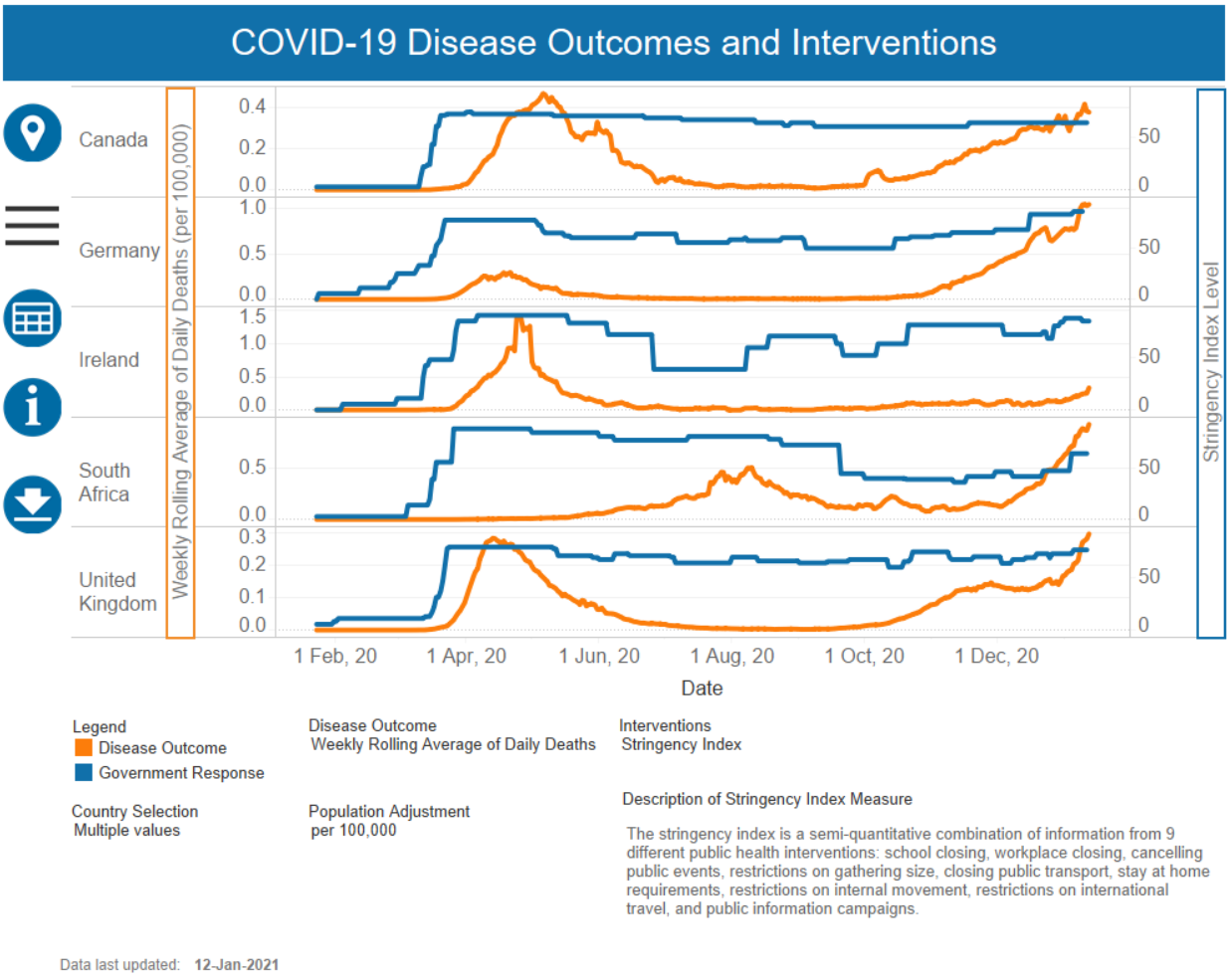


Figure 2. Canada and selected other countries; weekly rolling average of daily deaths of Covid-19 per 100,000 and interventions.

Provincial: See Figure 3.
Encouraging trends:
In Manitoba, there was a small decrease in the stringency index from 80 to 78 on January 4, 2021 (driven by relaxation of school closures), however the high level of stringency in place since late November continues to show a positive impact with the decrease in cases being sustained.

Troublesome trends:
In Saskatchewan, a dramatic increase in the weekly rolling average of daily cases has occurred since December 31, 2020 (2nd highest in Canada in terms of cases/100,000 population behind Quebec). As of January 11, 2021, there was a decrease in stringency from 62 to 56 driven by relaxation of school closures.

Trends to be monitored in light of stringency index values:
In both Ontario and Quebec, cases continue to increase. In Ontario, there was a decrease in stringency index from 73 to 71 as of January 11, 2021 due to targeted relaxation of school closures in northern Ontario. In Quebec on January 9, 2021, there was an increase in stringency from 70 to 74 due to implementation of a curfew followed

by a decrease in stringency index to 70 on January 11 because of a relaxation of school closures. In British Columbia, there has been a slight increase in cases since December 31, 2020 but overall, case numbers are holding steady. On January 7, 2021, there was an increase in stringency index from 61 to 70 driven by a targeted stay-at-home order. In Alberta, case numbers are generally holding steady. As of January 11, 2021, there was a decrease in stringency index from 69 to 62 due to relaxation of school closures.

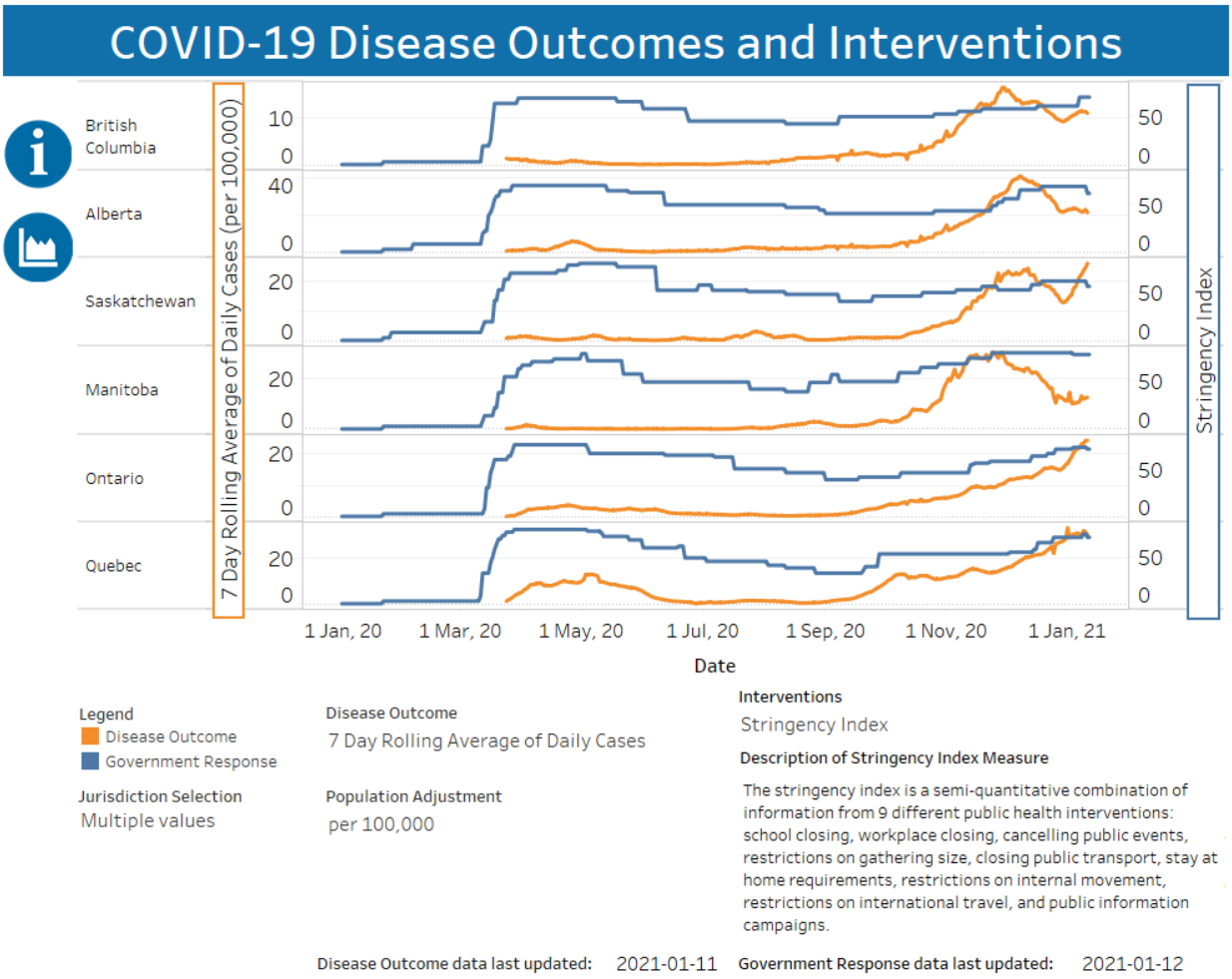


Figure 3. Provincial weekly rolling average of daily cases of Covid-19 per 100,000 and information on public health interventions (Data available up to Jan. 12th, 2021 (stringency index) and Jan. 11th, 2020 (cases)).

04 DYNAMIC MODELLING

MODELLING THE IMPACT OF AGE-STRATIFIED VACCINATION IN THE ABSENCE OF OTHER PUBLIC HEALTH MEASURES

Key Points

- Initial rollout of the SARS-CoV-2 vaccine will target older age groups and as an increasing number of older Canadians receive the vaccine, there is a need to identify whether vaccination alone can result in manageable levels of infection.
- This study explored the impact of vaccinating older individuals in the absence of other public health measures, assuming the use of a sterilizing vaccine and a non-sterilizing vaccine, both with a 95% efficacy rate. A minimal level of testing and contact tracing was implemented, but other public health measures such as physical distancing and community closures were lifted after individuals were vaccinated.
- All scenarios resulted in reduced clinical cases, hospitalizations, ICU admissions and deaths compared to the baseline scenario, and more substantial when the targeted age threshold included relatively young individuals (≥50 years old).
- Even with the assumption that all older individuals become fully vaccinated at the same time, vaccination alone was not sufficient to reduce hospitalizations and ICU admissions below the maximum Canadian hospital and ICU bed capacities.
- This study suggests that, in the absence of non-pharmaceutical public health measures, vaccinating vulnerable age groups does not result in manageable levels of severe infections

Background

The PHAC agent-based model was used to explore the impact of vaccinations targeted to older age groups on projected COVID-19 outcomes. Current NACI recommendations are for older more vulnerable age groups (as well as healthcare workers) to be prioritized for vaccination given the currently restrained vaccine supply and uncertainties as to the capacity of licensed vaccines to protect against infection (i.e. sterilizing) rather than simply protecting against disease (i.e. non-sterilizing). As more vulnerable people are vaccinated in Canada, it is possible that there will be reduced appetite to maintain restrictive measures by the public and businesses and there is, therefore, an urgent need to explore the consequences of releasing public health measures when limited sectors of the population become vaccinated. Here, we explored a simplistic implementation of vaccination in older age groups, assuming the use of a 1) sterilizing and 2) non-sterilizing vaccine, both with a 95% efficacy rate. Under the assumption that all targeted individuals become vaccinated on January 1, 2021 (i.e. a theoretical best case scenario for a vaccine rollout), we sought to explore the outbreak trajectory after these individuals become vaccinated and the remainder of additional non-pharmaceutical measures are relaxed.

Methods

Using the PHAC agent-based model [1], public health measures in a baseline scenario followed the baseline model assumptions fit to observed data and described in December 3rd 2020 PHAC modelling group report [2]. These included: 1) 20% of cases are detected and isolated, with 50% of the detected cases contact traced and

quarantined from March 16th, 2020, onwards; 2) three phases of lifting of community closures from March 16th, 2020 to September 7th, 2020; 3) three corresponding phases of physical distancing with change in compliance over the summer; and 4) an importation rate of one case per 100,000 population per week.

In addition to the baseline measures, the age-stratified scenarios explored the implementation of vaccinating individuals above three age thresholds (>49 years, >59 years, and >69 years). All individuals above the age threshold were assumed to become fully vaccinated on January 1st, 2021 with either a sterilizing (**scenario A**) or non-sterilizing (**scenario B**) vaccine:

1) **Scenario A (sterilizing vaccine):** all individuals above the age threshold have a 95% probability of developing immunity against infection following vaccination (i.e., immune individuals have a 0% probability of infection given contact with an infected individual) and cannot infect others after vaccination.
2) **Scenario B (non-sterilizing vaccine):** all individuals above the age threshold have a 95% probability of developing immunity against *symptomatic* infection (i.e., immune individuals have a 0% probability of developing symptoms if infected) and can infect others even though they are vaccinated.

In all scenarios closures and physical distancing were lifted at the time vaccinations were implemented. These scenarios were chosen to explore their impacts on the progression of the COVID-19 outbreak rather than provide recommendations for their implementation. For each scenario and for each age threshold, 200 model realizations were ran.

Results

A summary of the main output measures for each scenario is presented in Table 1.

Table 1. Main output measures presented as the median (95% credible interval) of 200 model realizations for each scenario.

		Sterilizing vaccination			Non-sterilizing vaccination		
	Baseline	Age >49	Age >59	Age >69	Age >49	Age >59	Age >69
Total attack rate (%)	41.0 (39.6-42.3)	27.2 (21.8-33.6)	34.8 (32.7-37.8)	39.2 (37.7-40.7)	41.7 (40.4-42.9)	41.4 (40.1-42.7)	41.1 (39.7-42.3)
Clinical attack rate (%)	25.0 (24.25.8)	16.0 (12.7-20.2)	20.8 (19.4-22.7)	23.7 (22.6-24.7)	20.6 (19.2-22.3)	22.8 (21.6-23.9)	24.2 (23.2-24.9)
Mortality rate (%)	2.9 (2.7-3.1)	1.3 (0.5-2.2)	1.4 (0.8-2.2)	1.9 (1.5-2.4)	1.1 (0.5-1.9)	1.2 (0.8-2.1)	1.9 (1.3-2.3)
Hospitalizations per 100,000	2981 (2821-3128)	1357 (884-2050)	1916 (1606-2427)	2482 (2299-2739)	1657 (1297-2178)	2073 (1788-2472)	2544 (2359-2758)
ICU admissions per 100,000	663 (602-711)	288 (177-463)	422 (337-531)	566 (504-629)	347 (253-4868)	451 (383-548)	580 (530-630)
Days hospital beds overcapacity	164 (146-177)	117 (87-129)	143 (130-158)	154 (141-167)	136 (114-150)	148 (133-163)	157 (145-169)
Days ICU beds overcapacity	147 (130-163)	90 (34-109)	123 (107-142)	139 (122-155)	114 (83-132)	130 (109-145)	140 (126-155)
Outbreak duration (days)	506 (455-468)	483 (422-438)	496 (447-463)	503 (452-467)	495 (451-466)	500 (453-465)	499 (454-471)

Compared to the baseline scenario, all scenarios were effective in reducing the clinical attack rate in the population. The most substantial reduction in incidence was observed when the age threshold was set relatively low (>49 years). The total attack rate in the non-sterilizing vaccination scenario was slightly higher than in the baseline due to the assumption that this type of vaccine allows asymptomatic infections, preventing those individuals from being detected and isolated, which they would have been had they not been vaccinated.

All scenarios resulted in reduced incident clinical cases, hospitalizations, ICU admissions and deaths compared to the baseline scenario (Fig 1-4). As the age threshold increased, the effectiveness of the implemented vaccination strategy diminished for all outcomes. For instance, there was a minimal reduction in severe outcomes when only individuals over the age of 69 were vaccinated. Furthermore, even when the age threshold was reduced to include relatively young individuals (>49 years), neither scenario resulted in a manageable level of infections: hospital and ICU beds substantially exceeded the maximum Canadian hospital bed capacity (30 bed per 100,000[2]) and ICU bed capacity (9 per 100,000[1]), and the total duration of the outbreak was not impacted. The results suggest that if an age-stratified vaccination approach is to be considered, additional public health measures for the remainder of the population must be maintained in parallel to avoid devastating impacts resulting from the spread of SARS-CoV-2 in the Canadian population.

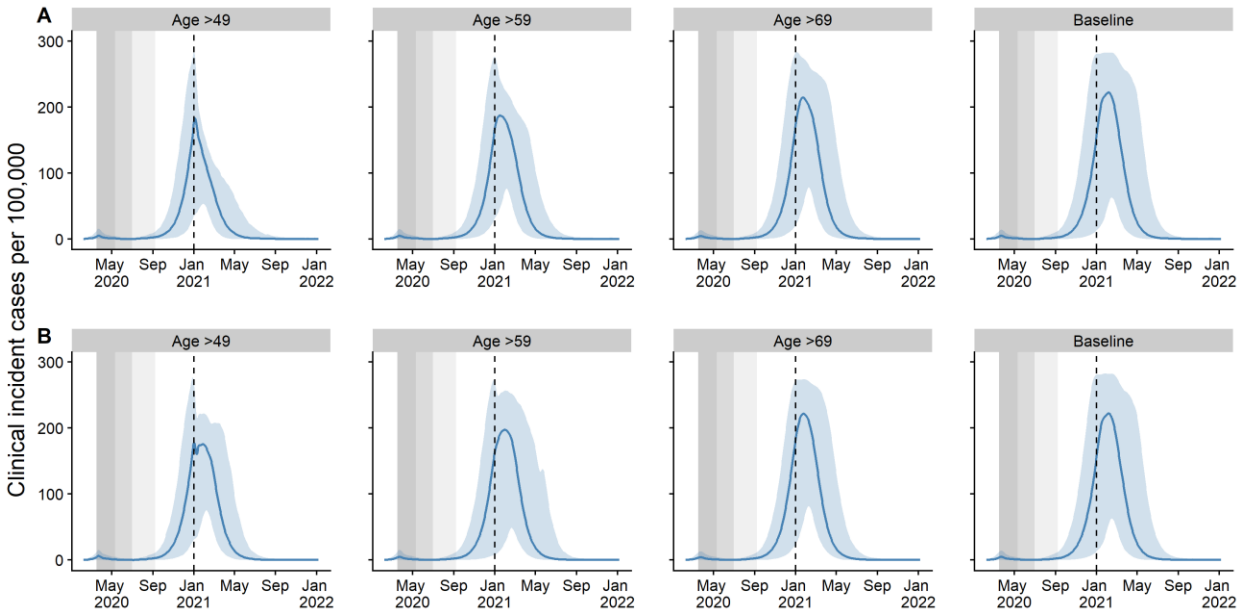


Figure 1. Projected daily incidence of clinical cases per 100,000 people following the administration of **A**) a sterilizing vaccine and **B**) a non-sterilizing vaccine for different age thresholds in comparison with the baseline scenario (no vaccination). The black dashed line represents the day of vaccination. The gray shaded zones represent the three phases of community closures and social distancing. The blue curve and blue shaded area represent the smoothed median and 95% credible intervals, respectively.

[2] Based on data provided by Health Canada in August 2020

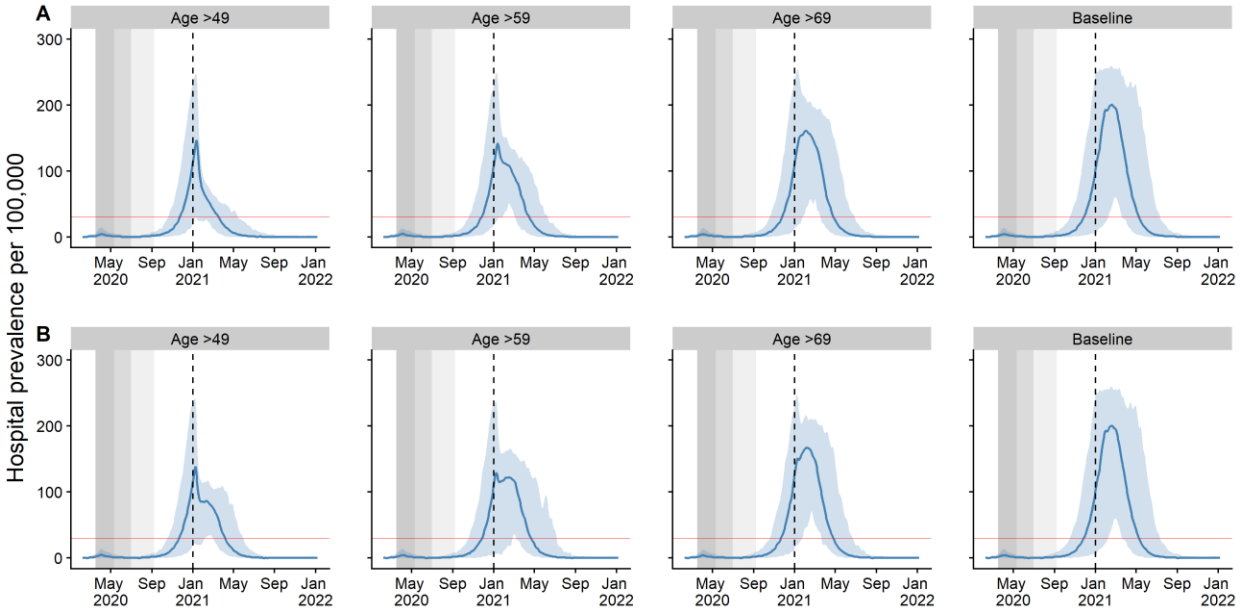


Figure 2. Projected daily hospital admission prevalence per 100,000 people following the administration of **A**) a sterilizing vaccine and **B**) a non-sterilizing vaccine for different age thresholds in comparison with the baseline scenario (no vaccination). Prevalent cases include general hospital admission and pre-ICU and post-ICU hospital admission. The black dashed and red lines represent the day of vaccination and the maximum Canadian hospital capacity, respectively. The gray shaded zones represent the three phases of community closures and social distancing. The blue curve and blue shaded area represent the smoothed median and 95% credible intervals, respectively.

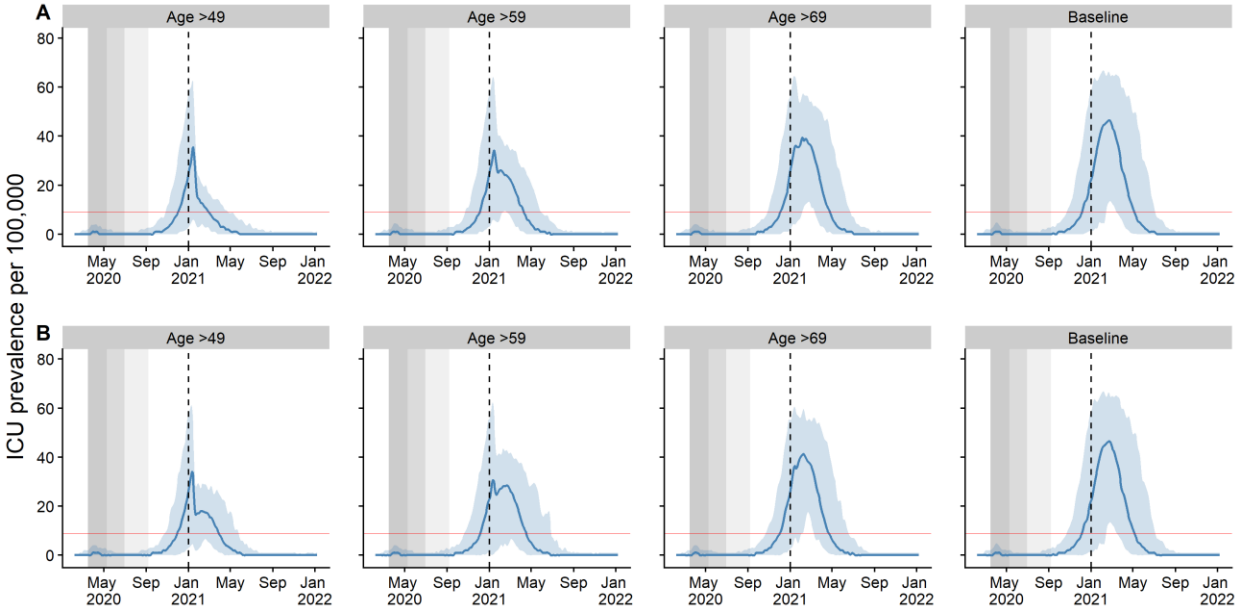


Figure 3. Projected daily intensive care unit (ICU) prevalence per 100,000 people following the administration of **A**) a sterilizing vaccine and **B**) a non-sterilizing vaccine for different age thresholds in comparison with the baseline scenario (no vaccination). The black dashed and red lines represent the day of vaccination and the maximum Canadian ICU bed capacity, respectively. The gray shaded zones represent the three phases of community closures

and social distancing. The blue curve and blue shaded area represent the smoothed median and 95% credible intervals, respectively.

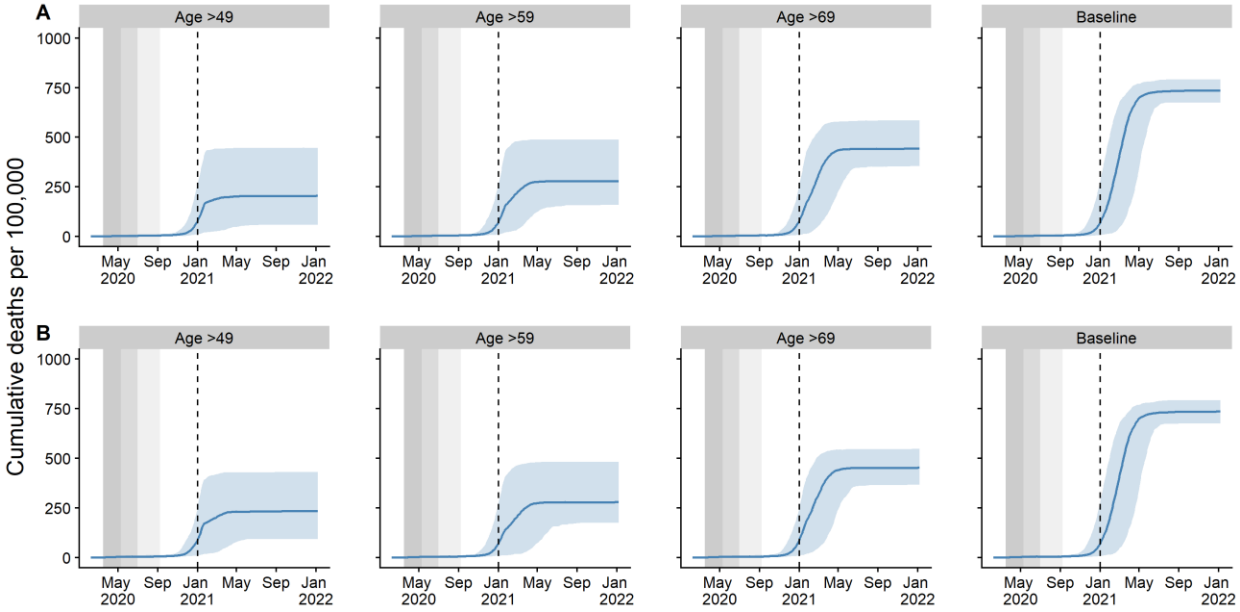


Figure 4. Projected cumulative deaths per 100,000 people following the administration of **A**) a sterilizing vaccine and **B**) a non-sterilizing vaccine for different age thresholds in comparison with the baseline scenario (no vaccination). The black dashed line represents the day of vaccination. The gray shaded zones represent the three phases of community closures and social distancing. The blue curve and blue shaded area represent the smoothed median and 95% credible intervals, respectively.

Limitations

- All interventions are applied on the same day (January 1st, 2021), resulting in all individuals over the age threshold becoming vaccinated at the same time.
- Individuals that recover from the disease are assumed to become immune against infection for the duration of the model run. Similarly, immunity acquired from a sterilizing or non-sterilizing vaccine is assumed to last for the duration of the model run.
- Asymptomatic individuals are as infectious as symptomatic individuals.

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1. Ng, V., Fazil, A., Waddell, L.A., Bancej, C., Turgeon, P., Otten, A., Atchessi, N., and Ogden, N.H. (2020). "Projected effects of non-pharmaceutical public health interventions to prevent resurgence of SARS-CoV-2 transmission in Canada" Canadian Medical Association Journal, 192(37): p. E1053-E1064.
2. Public Health Agency of Canada (2020). "COVID-19: PHAC modelling group report" December 3rd 2020, 72 pages.

MODELLING THE IMPACT OF THE NEW VARIANT STRAIN AND THE SPEED AND COVERAGE OF VACCINATION IN THE CANADIAN POPULATION

Key points

- A more transmissible strain of SARS-CoV-2 will result in the epidemic being harder to control, even if vaccines are available
- Our current rate of vaccination is insufficient to control the epidemic; we will need to increase vaccination efforts significantly to see the impact of the vaccine on the epidemic
- Increasing vaccination rates will reduce clinical cases, hospitalizations and deaths but vaccination is not adequate to control the epidemic without additional measures
- Even with regular shutdowns, if we do not enhance other public health interventions, vaccination will only reduce the epidemic minimally
- The best scenario against a more transmissible strain of SARS-CoV-2 was a combination of high vaccination rate, wide coverage across ages and no shortages during the epidemic

Background

The PHAC agent-based model was used to explore two recent COVID-19 developments: the emergence of a new variant strain of SARS-CoV-2 (VOC 202012/01) that is potentially up to 70% more transmissible from person-to-person than the original strain [1] and the recent approval and administration of the vaccine to the most vulnerable Canadian population. To date, approximately 400,000 Canadians have been vaccinated since December 14, 2020; this is on average 13,219 individuals per day [2]. In this analysis, we explore the impact of the VOC 202012/01 strain introduced into the population over the second year of the epidemic in Canada, the impact of a vaccination program administered at the current rate, and two other rates under the assumption that our current levels of interventions remain insufficient to control the epidemic and with the new variant strain dominating transmission in 2021.

Methods

We modified the PHAC agent-based model to assess the introduction of a more contagious strain and an age-stratified temporally variable vaccination program. The methods for the model have been published (reference in the annexes). We compared five models in this analysis:

Scenario 1: baseline
The baseline is estimated on our current level of public health interventions and fitted to Canadian data (see December 3, 2020 modelling report. In addition, we assume an importation rate of one case per 100,000 per week. As our current levels of interventions are insufficient, we allow regular shutdowns to occur from September 8, 2020 when cases reach 100 active cases per 100,000 for 42 days at a time.

Scenario 2: introduction of a more transmissible strain
In addition to the baseline public health measures, we apply a logistic growth function with the assumption that 10% of cases on January 1, 2021 are caused by the more transmissible strain leading to a gradual increase in the proportion of cases over time in the population. By the end of 2021, the strain dominates and all cases are transmitted at 70% of the current estimated value.

Scenario 3: vaccination of 65 and over at the current rate
In addition to the baseline measures and introduction of a more transmissible strain in Scenario 2, this scenario explored the administration of vaccination to individuals 65 years and over at the current vaccination rate (36 per 100,000 daily). Each day, we vaccinate 36 individuals, full immunity is acquired after 28 days and life-long immunity is conferred in these individuals. The vaccine is assumed to be sterilizing so that immune individuals have 0% probability of infection upon contact with an individual once immunity is conferred. During the 28 days while building up immunity, individuals can be infected at a linear rate proportional to the day of vaccination so that the probability of infection decreases with increasing number of days post-vaccination. Because of the slow vaccination administration rate, there are more individuals awaiting vaccination at the end of the model run.

Scenario 4: vaccination of 65 and over at double the current rate
Individuals are vaccinated at a rate of 72 per 100,000 daily, double our current rate in Canada. This is equivalent to vaccinating approximately 27,000 individuals per day across Canada. At this rate, we assume we run out of vaccines for other age groups and stop vaccinating once all 65 years and over are vaccinated.

Scenario 5: vaccination of 65 and over at five times the current rate
Individuals are vaccinated at a rate of 180 per 100,000 daily, five times our current rate in Canada. This is equivalent to vaccinating approximately 67,500 individuals per day across Canada. At this rate, we assume we run out of vaccines faster compared to Scenario 4 for other age groups and stop vaccinating once all 65 years and over are vaccinated.

Scenario 6: vaccination of 50 and over at five times the current rate
Individuals are vaccinated at a rate of 180 per 100,000 daily, double our current rate in Canada. We do not run out of vaccines and start vaccinating all individuals from 50 years and over.

Results

Table 1 is a summary of the main model outputs for each scenario. A more transmissible variant strain is anticipated to increase the total number of cases, hospitalizations and deaths. Under this scenario, even the regular shutdowns that are implemented is not sufficient control the epidemic (Figure 1). All vaccination scenarios explored reduced cases, hospitalizations and deaths significantly compared to the variant strain scenario with increasing rates of administration resulting in decreasing health outcomes.

Table 1. Main model outputs presented as median values with 95% credible intervals. Each scenario represents 50 model realizations.

			Vaccination scenarios modelled on variant strain scenario			
			65 years & over	**65 years & over**	**65 years & over**	**50 years & over**
Summary statistics	**Baseline**	**Variant strain**	**Current rate (36 per 100,000 daily)**	**72 per 100,000 daily**	**180 per 100,000 daily**	**180 per 100,000 daily**
Total attack rate (%)	8.0 (5.9-11.8)	23.0 (13.4-34.9)	21.9 (11.6-32.5)	19.9 (10.3-33.4)	19.7 (10.3-28.5)	13.3 (9.0-21.0)
Clinical attack rate (%)	4.9 (3.6-7.2)	14.2 (8.2-21.6)	13.4 (7.0-20.0)	12.0 (6.2-20.4)	11.9 (6.1-17.4)	7.8 (5.3-12.5)
Case fatality rate (%)	1.4 (1.1-1.7)	2.7 (1.9-3.2)	2.0 (1.3-2.6)	1.4 (0.8-2.0)	1.0 (0.6-1.3)	0.8 (0.6-1.2)
Infection fatality rate (%)	0.9 (0.6-1.1)	1.6 (1.2-2.0)	1.2 (0.8-1.6)	0.9 (0.5-1.2)	0.6 (0.3-0.8)	0.5 (0.4-0.7)
Acute hospitalizations per 100,000	377 (264-569)	1181 (679-1865)	1010 (483-1536)	811 (398-1482)	726 (389-1068)	452 (283-700)
ICU admissions per 100,000	127 (88-190)	401 (223-642)	352 (182-559)	289 (147-515)	280 (123-404)	154 (100-229)
Total vaccinated	N/A	N/A	13392 (13392-13392)	17242 (16655-17502)	17486 (17250-17697)	36821 (35540-37350)
Vaccination end day (from 700 model days)	N/A	N/A	Ongoing at model end	568 (560-572)	426 (424-427)	544 (537-547)

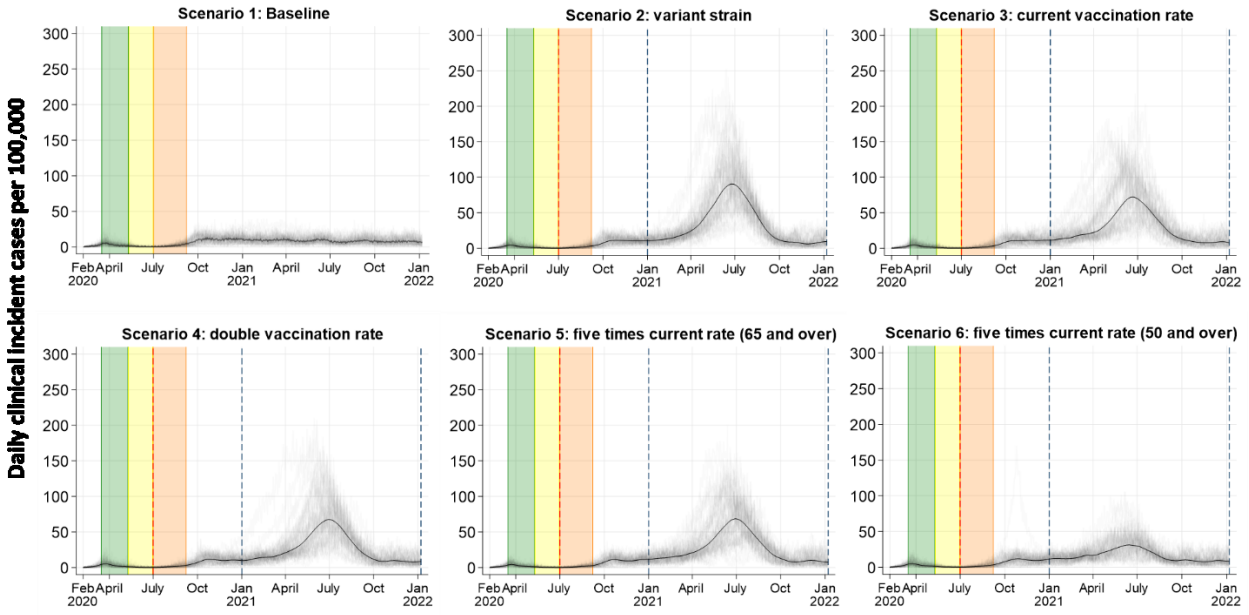


Figure 1. Daily clinical incident cases per 100,000 for each scenario. Grey lines represent 50 model realizations, the black line represents the median values.

Our findings indicate that a more transmissible strain of SARS-Cov-2 will be harder to control, even if vaccines are available. Our current rate of vaccination is insufficient given our current levels of interventions. As such, although the vaccine is now available in Canada, the current rate of vaccination is not sufficient to help control the epidemic, even with regular shutdowns. In order to control the epidemic, we will need to enhance current public health measures including case detection and isolation, contact tracing and quarantining and personal physical distancing. At the same time, and while keeping interventions enhanced, we need to ensure we have a continual supply of vaccines and increase our current vaccination rate.

Limitations

- We assume the vaccine is 100% efficacy in all age groups and that there is no waning immunity
- We assume public health interventions will no change from the baseline
- Asymptomatic individuals are as infectious as symptomatic individuals.

References

1. Volz, E., S. Mishra, M. Chand, J.C. Barrett, R. Johnson, L. Geidelberg, W.R. Hinsley, D.J. Laydon, G. Dabrera, Á. O'Toole, R. Amato, M. Ragonnet-Cronin, I. Harrison, B. Jackson, C.V. Ariani, O. Boyd, N.J. Loman, J.T. McCrone, S. Gonçalves, D. Jorgensen, R. Myers, V. Hill, D.K. Jackson, K. Gaythorpe, N. Groves, J. Sillitoe, D.P. Kwiatkowski, S. Flaxman, O. Ratmann, S. Bhatt, S. Hopkins, A. Gandy, A. Rambaut, and N.M. Ferguson, *Transmission of SARS-CoV-2 Lineage B.1.1.7 in England: Insights from linking epidemiological and genetic data.* medRxiv, 2021: p. 2020.12.30.20249034.
2. Our World In Data, *COVID-19 vaccination doses administered per 100 people, Jan 13, 2021*. 2011.

THEORETICAL SCENARIO PROJECTIONS FOR SARS-COV-2 VARIANT OF CONCERN B.1.1.7 INTRODUCTION INTO PROVINCES IN CANADA

Key points

- Long term projections of reported cases for major Provinces were developed using different levels of initial fractions of the population infected with the variant of concern (VoC)
- The projections suggest that the epidemic would accelerate markedly in all provinces with introduction and expansion of the VoC, and in the absence of enhanced public health measures.
- The most recent surveillance data are not consistent with the VoC being at a high prevalence in COVID-19 cases in Canada in recent months.
- However, it is possible that the VoC will expand in Canada and result in an accelerating epidemic in the coming months.

Background

In December 2020, an initial analysis of the rapid outbreak of a new detected variant (B.1.1.7, also termed VOC-202012/01) in the UK has brought major concerns globally. This analysis suggested that this new variant of concern (VoC) has the possibility to be more transmissible (up to 70%) than current strains. Here we produced a set of projections for the COVID-19 epidemic, assuming different initial fractions of COVID-19 infections in Canada were of the VoC in mid-December 2020.

Methods

The model is a SEIR model with additional compartments reflecting the biology of COVID-19 and relevant aspects of the health care system and public health response. Incidence is proportional to the effective transmission rate β(t), a time-varying function that incorporates piecewise changes on specified dates associated with the changes in implementation of public health measures that have occurred in individual provinces. For specific details on the model, see Nov-19 modelling report (A New SEIR Compartmental Model with Health Care Systems and Testing Regimes, 2020-11-19).

To account for the possible introduction of VoC, the effective transmission rate β(t) of the projections is modeled using a logistic-based saturating function where the minimum is the last ensemble of β(t), and the maximum is 70% increase in β(t). This formulation depends on the initial fraction of VoC in the *infected* population; thus, we selected three different levels: 1 out of 100, 1 out of 10,000 and 1 out of 1 million infected individuals being infected with VoC. This formulation does *not* model VoC explicitly, but the overall effect of a possible increase of the effective transmission rate by 70%.

In addition, we included all public health measures in the calibration prior to Dec 18th, and we did not include any upcoming holiday effects and public health measures beyond Dec 18th for all provinces. We calibrate using

maximum likelihood estimation (MLE) by matching deterministic trajectories to the reporting time series from Sept 15th to Dec 18th 2020 and assume negative binominal observation error. We then use the calibrated model and project 300 realizations 90 days ahead.

Results

Figure 1 shows the 90 day projections for 6 out of 10 provinces with three different new strain introduction fractions as of December 19th (1 in 100, 1 in 10,000, and 1 in 1). 95% confidence prediction intervals are calculated by taking the 2.5% and 97.5% quantiles of ensemble realizations. These projections suggest that we would expect large expansions of the epidemic in the absence of enhanced control measures once the new strain becomes prevalent (i.e. the effective transmission rate continues to increase up to 70%). The lower the initial fraction infected with the VoC, the longer the trajectories would take to diverge. When comparing against recent surveillance data, there is no clear signal of increases in the effective transmission rate compared to the null model without VoC. However, we are currently at the earliest period that we would expect to see a diverging, accelerating epidemic due to the VoC if prevalence of infections with VoC in December were at low prevalence.

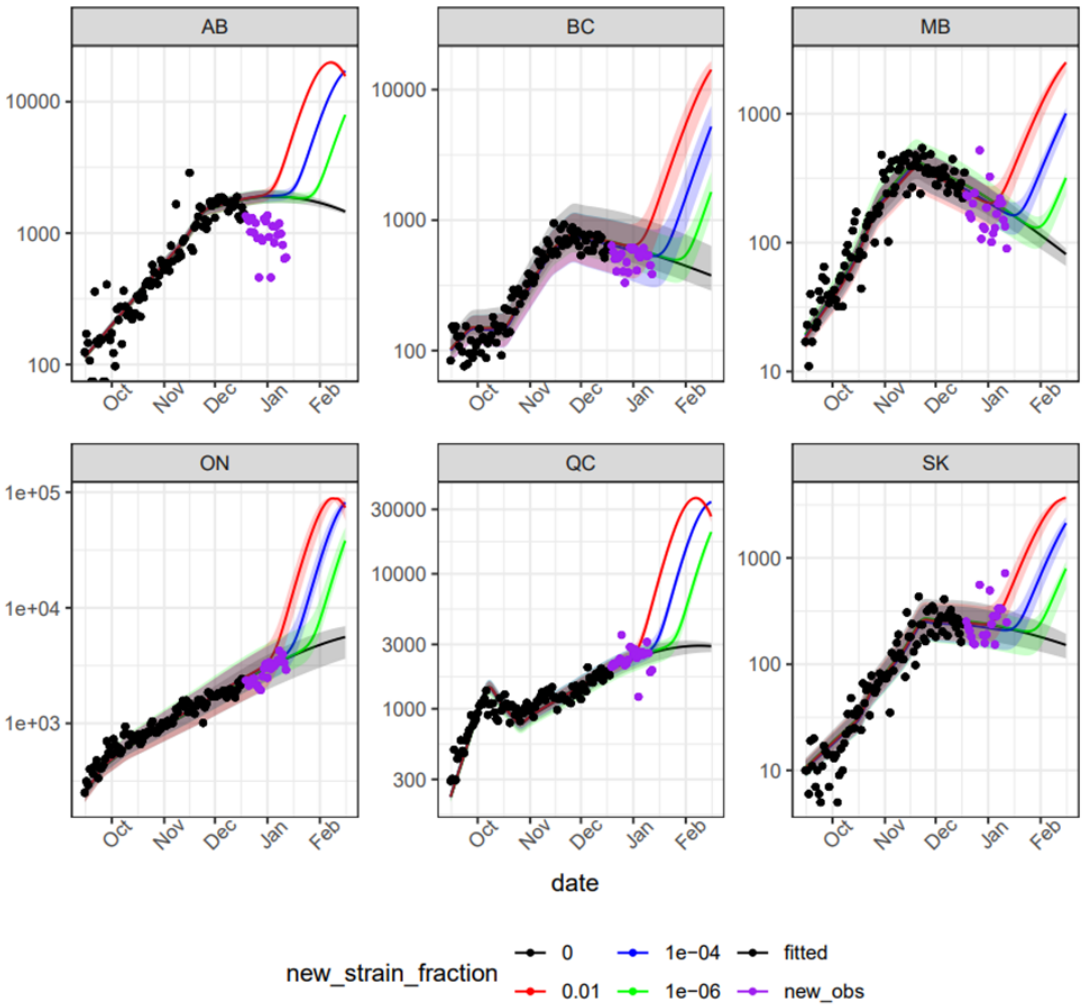


Figure 1. 90 days projections with 95% prediction intervals of reported cases for major Canadian provinces with three different levels of VoC introductory fraction. Black points are the fitting window and purple points are recently observed reported cases. The black graph line is the projection, without the VOC, that is fit to surveillance data up to 18th December (black points). The red, blue and green graph lines show the forecast assuming that on 19th December the proportion of infections that are the new VoC is, respectively, 1 in 100 in red, 1 in 10,000 in blue, and 1 in 1 million. Mauve points indicate surveillance data from 19th December

Limitations

This is an ad-hoc theoretical exploration from our calibrations, translating the potential effects of VoC invasion using effective transmission rates starting in mid-December. The projections did not account for the upcoming holiday effects that can contribute to the increase in reported cases we are observing. Hence it is difficult to disentangle the effect of behavior change during the holidays and the potential increase in transmissibility from the VoC. The projections also do not account for more recent enhancements to public health measures in Quebec and Ontario.

Conclusion

The projections suggest that the epidemic would accelerate markedly in all provinces with introduction and expansion of the VoC, and in the absence of enhanced public health measures. The most recent surveillance data are not consistent with the VoC being at a high prevalence in COVID-19 cases in Canada in recent months. However, it is possible that the VoC will expand in Canada and result in an accelerating epidemic in the coming months.

THE IMPACT OF THE EMERGENCE OF THE UK COVID-19 STRAIN B 1.1.7 (VOC-202012/01), AND WANING IMMUNITY ON THE CURRENT EPIDEMIC IN CANADA

Key points

- Model simulations of the potential emergence of a new, more transmissible strain of COVID-19 (VOC-202012/01) in Canada suggest a large potential third wave of cases and hospitalizations in 2021.
- Using waning immunity ranges (6-10 months) based on early studies, our simulations suggest that waning immunity will likely not play a significant in role the epidemic at this time in Canada in comparison with the emergence of the new UK variant and speed of this strain becoming the dominant strain in transmission in Canada.
- The emergence and establishment of this new strain provokes a dramatic increase in the final attack rate as well as a much higher possible third wave of cases and hospitalizations if physical distancing is gradually released with warming weather in 2021.
- The results show us that implementing rapid vaccination and/or maintaining a high level of public health measures such as high levels of physical distancing will be necessary to avoid a third wave in 2021.

Background

The two transmission phenomena of waning immunity as well as the emergence of new, more transmissible strains are realities that we are currently facing in the context of the COVID-19 pandemic, in Canada, and elsewhere around the world. The objective of this report is to study the combined effect of these two phenomena on the current course of the epidemic in Canada, independently of vaccination which is gradually being rolled out and which will have a significant impact on these results in the future.

Methods

A compartmental model (Ludwig et al. 2020) was adapted, as described in the Annexe, to simulate the potential effects of using waning immunity in the context of the emergence of a new COVID_19 variant.

Model parameters were obtained from the literature and (for contact rates, case detection rates, percentage of contacts traced and quarantined, transmission coefficient when people make contact, as well as the time delay until isolation of cases) fit to surveillance and hospitalisation data in Canada. By so doing, the model simulated the observed epidemic up to day 329 of the epidemic (January 1st 2021), at which time, different scenarios for introduction of a new strain and waning immunity were introduced.

The objective of this work is to examine the combined effect of waning immunity and the emergence of the new UK strain on the current course of the epidemic in Canada.

What's new?

Modelling waning immunity

We observe that re-infection is now possible for previously infected individuals, although how frequently it occurs is not yet known. Following results obtained from a cohort study of Health Care workers in the UK, we used values for the duration of post-infection protective immunity of 6, 8, or 10 months (Hanrath, 2021, Lumley 2021). Waning immunity was introduced starting day one of the epidemic for the current simulations.

Modelling the emergence of the new strain

We are currently facing the emergence and spread of a new UK variant (VOC-202012/01, termed VoC in the following) that appears to be more transmissible than the current active variant in Canada. Recent reports suggest a transmissibility risk ~1.5 times (up to 1.7 times) higher for the VoC in comparison with previously circulating strains (Public Health England, 2021). We modelled the emergence and establishment of the VoC according to 3 scenarios: the VoC emerges and becomes dominant in Canada within 3 months, 4.5 months, and 6 months.

The emergence and establishment of the VoC is modelled with a general incremental increase of the transmission coefficient (beta) from the best fit value obtained on Dec 23rd to 1.5 times this value after 3, 4.5 or 6 months respectively following its introduction on Jan 1st 2021 (**see Figure 1**).

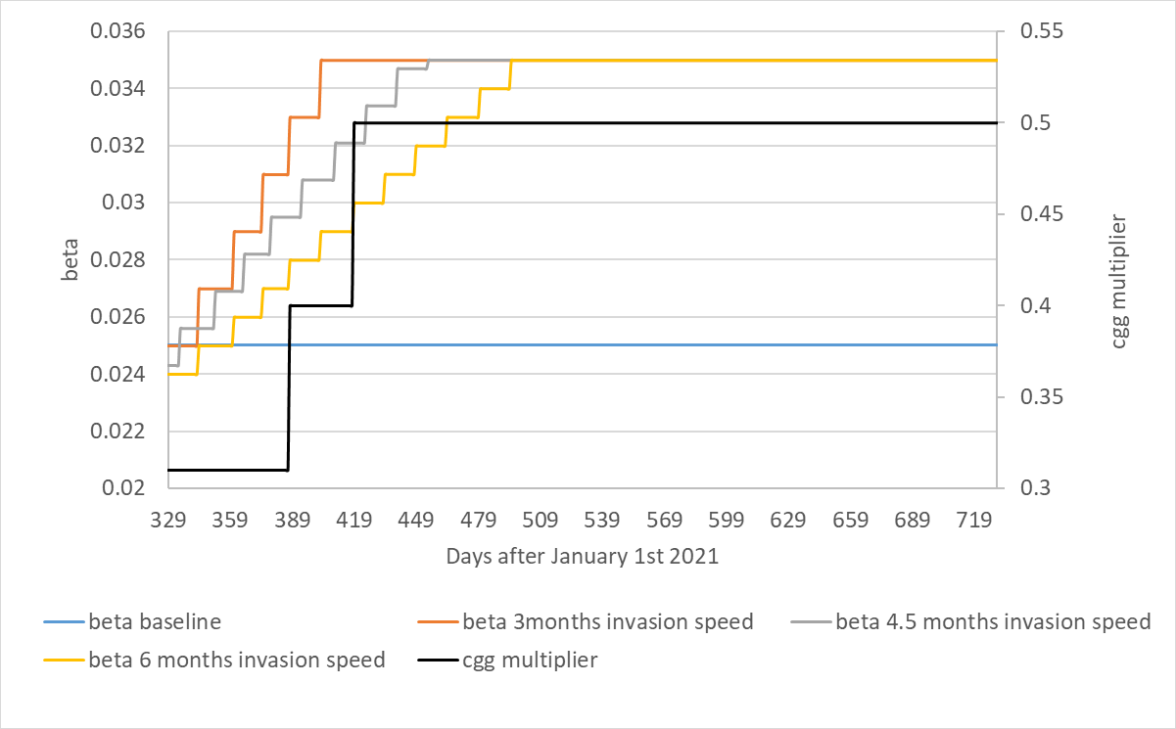


Figure 1. Variation of beta (transmission probability upon contact) and cgg multiplier (level of physical distancing in comparison with pre-covid values) for the 12 scenarios, after January 1st, 2021.

Additionally, the average number of contacts per individual was modified as follows: contacts were kept at 30% of their pre-epidemic value (corresponding to the best fit value on Dec 23rd), until the end of February. After

that date, we slowly released physical distancing measures to 40% of pre-epidemic values during March and 50% of pre-epidemic values starting in April until the end of the simulation (see **Figure 1**).

Using results obtained from our previous studies regarding test sensitivity, we kept delta, which represents the combination of the test sensitivity * the chance to be tested when infectious, constant from the best fit value obtained Dec 23rd until the end of simulation. In parallel, we chose to maintain the contact tracing rate and the delay between symptom onset and case detection/isolation fixed to the best fit values obtained for Dec 23rd until the end of the simulation.

All scenarios were run for 730 days. As outcomes, we calculated the daily incidence of observed and true infected cases, the prevalence of hospitalized cases, and the cumulative hospitalized cases, by scenario, until day 730. In summary, our 12 scenarios were as follows:

Table 1.Scenario definitions

Scenario	VoC invasion speed	Waning immunity
1	No invasion	6 months
2	3 months	6 months
3	4.5 months	6 months
4	6 months	6 months
5	No invasion	8 months
6	3 months	8 months
7	4.5 months	8 months
8	6 months	8 months
9	No invasion	10 months
10	3 months	10 months
11	4.5 months	10 months
12	6 months	10 months

Results

Observed and true case incidence

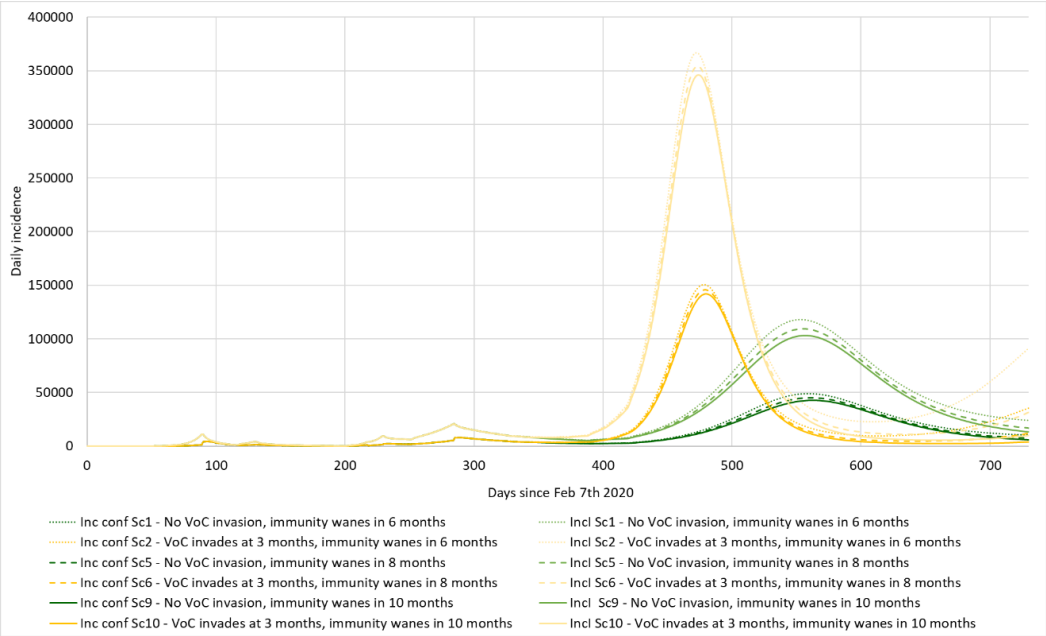


Figure 2. Comparison of the daily incidence of true cases (diluted color) and detected cases (full color) between the scenario 1, 5 and 9 (no VoC invasion) (green) and scenario 2, 6, 10 (yellow – VoC invasion speed of 3 months).

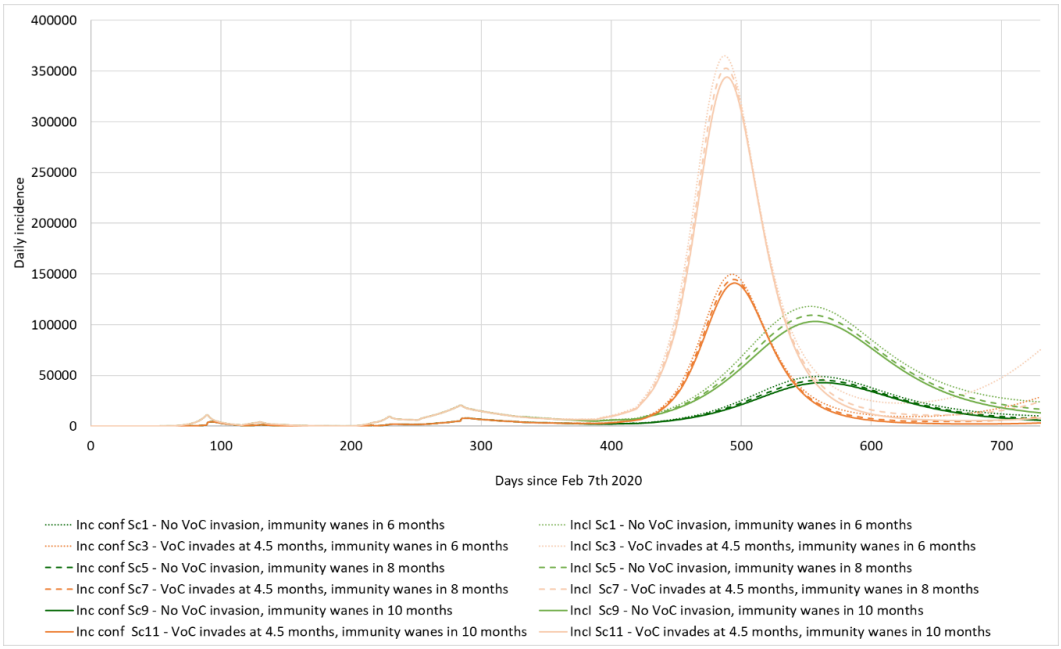


Figure 3. Comparison of the daily incidence of true cases (diluted color) and detected cases (full color) between the scenario 1, 5 and 9 (no VoC invasion) (green) and scenario 3, 7, 11 (orange - VoC invasion speed of 4.5 months).

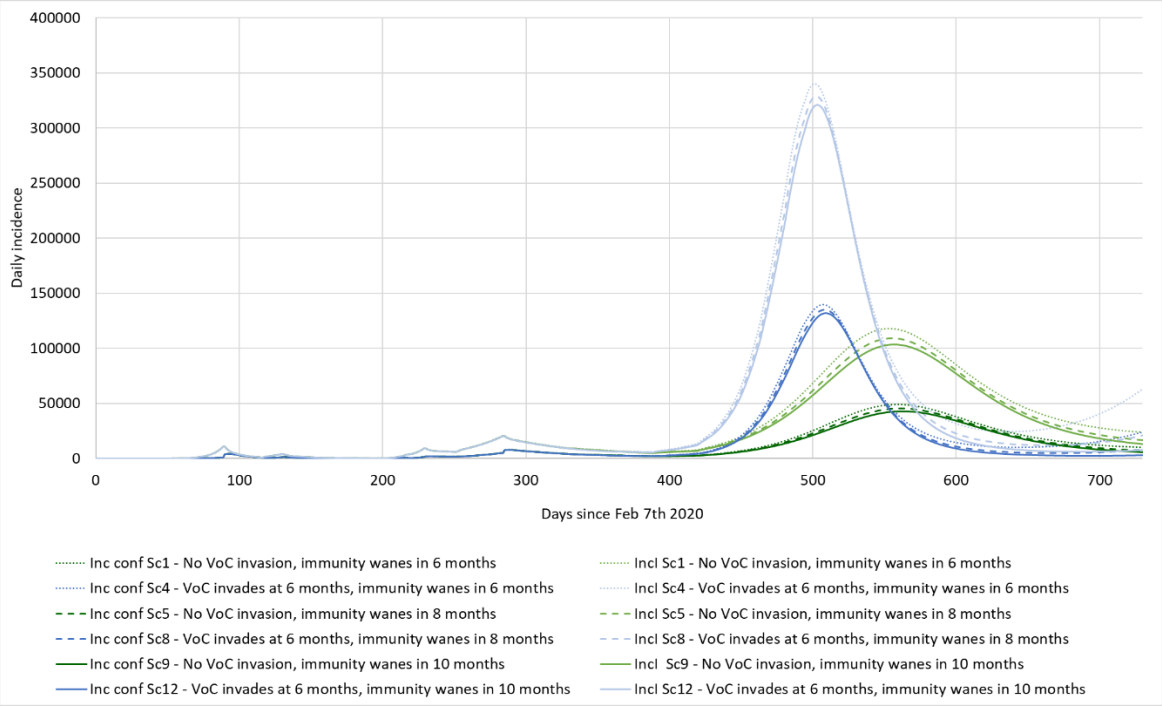


Figure 4. Comparison of the daily incidence of true cases (diluted color) and detected cases (full color) between the scenario 1, 5 and 9 (no VoC invasion) (green) and scenario 4, 8, 12 (blue – VoC invasion speed of 6 months).

Table 2. Attack rates at day 730 of the simulations for each scenario

Scenario	VoC invasion speed	Waning immunity	Attack rate (at day 730)
1	No invasion	6 months	28.9%
2	3 months	6 months	52.7%
3	4.5 months	6 months	52.7%
4	6 months	6 months	51.9%
5	No invasion	8 months	29.7%
6	3 months	8 months	53.7%
7	4.5 months	8 months	53.6%
8	6 months	8 months	53.9%
9	No invasion	10 months	30.2%
10	3 months	10 months	54.4%
11	4.5 months	10 months	54.3%
12	6 months	10 months	53.6%

We observe that the baseline scenarios (Scenarios 1,5, and 9), without any VoC introduction, lead to a third epidemic wave in late summer 2021, due to a partial release of physical distancing measures as the weather warms in the spring. The total attack rate for these scenarios varies between 28.9% and 30.2%, depending on the duration of waning immunity. Waning immunity does not seem to play a significant role in modifying the case curve shape nor the final attack rate at this time in Canada.

The third wave becomes more severe as the VoC is introduced. The speed of invasion has a small influence on the peak date for this third wave (the slower the invasion speed, the later the peak occurs), but does not appear to play a major role on the incidence peak height nor on the attack rate (average of 53.42% +/-0.8). The average attack rate with the VoC increases by around 20% in comparison with the baseline scenarios.

Waning immunity variations for scenarios with the VoC does not seem to modify these effects significantly.

Prevalence of hospitalization

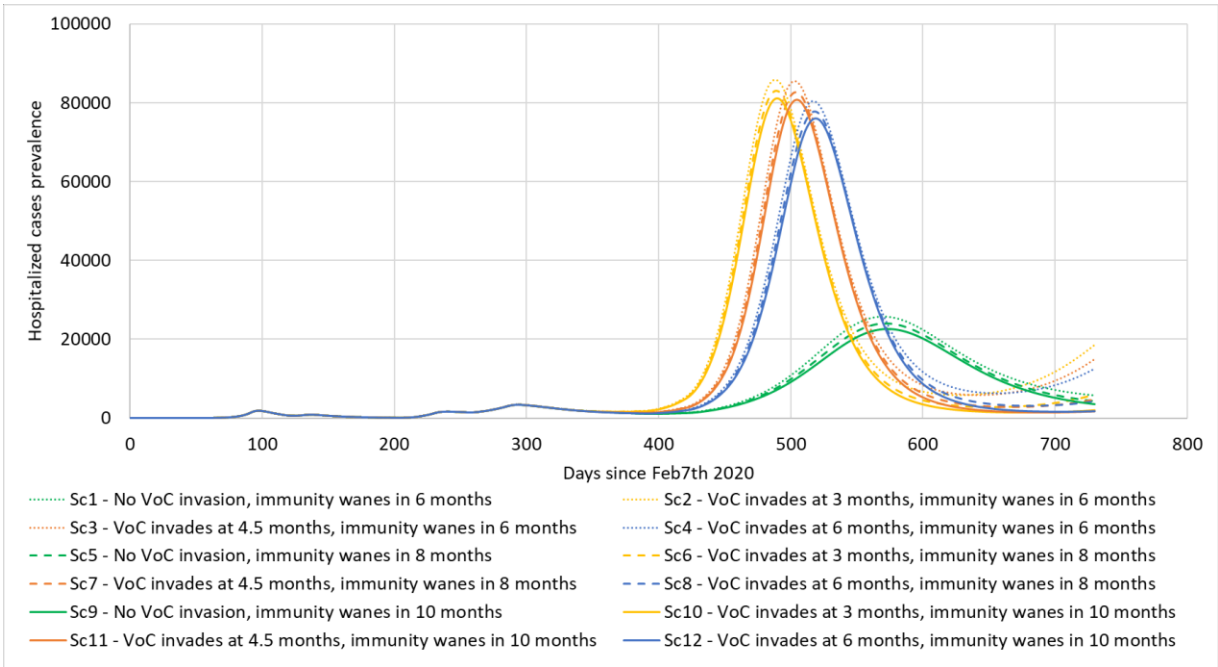


Figure 5. Comparison of the prevalence of hospitalized cases of true cases (diluted color) and detected cases (full color) among scenarios 1, 5 and 9 (no VoC invasion) (green) and scenarios 4, 8, 12 (blue).

The prevalence of hospitalized cases evolves in the same direction as the number of cases, with a third wave peak much higher for scenarios that include the VoC compared to those without. Waning immunity does not appear to have a significant effect on hospitalized cases. Similarly, the speed of emergence of the VoC does not seem to significantly modify the shape and size of the third wave peak, although the timing of the peak occurs earlier with more rapid invasion speeds.

Conclusion

The two transmission phenomena of waning immunity as well as the emergence of a new, more transmissible strain are realities that we are currently facing in the context of the COVID-19 pandemic.

The objective of this work was to study the combined effect of these two phenomena on the current course of the epidemic in Canada, independently of the vaccination which is gradually being rolled out and which will likely have a significant impact on these results in the future.

Our results show that waning immunity does not appear to play a significant role in epidemic unfolding during the timescales studied here in comparison with the speed of emergence of a new, more transmissible variant. The later provokes a dramatic increase in the total final attack rate as well as on the size of a possible third wave (in the case of future partial physical distancing releasing) in late summer 2021.

The results suggest that maintaining strict public health measures implementing during vaccine rollout will be necessary to avoid a third wave in 2021.

References

Hanrath, A. T., B. A. I. Payne, et al. (2020). "Prior SARS-CoV-2 infection is associated with protection against symptomatic reinfection." Journal of Infection.

Lumley, S. F., D. O'Donnell, et al. (2020). "Antibodies to SARS-CoV-2 are associated with protection against reinfection." medRxiv: 2020.2011.2018.20234369.

Public Health England. (2021). Investigation of novel SARS-CoV-2 variant Variant of concern 202012/01 - Technical Briefing 3. P. H. England: 19 pages. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/950823/Variant_of_Concern_VOC_202012_01_Technical_Briefing_3_-_England.pdf

05 SPECIAL REPORT

NOTES ON THE ANALYSIS OF COVID-19 TESTING DATA

Key points

- Analysis of testing data, including assessment of changes in positivity rates, has become a routine part of our exploration of the course of the COVID-19 epidemic.
- Simple assessments of changes in numbers of positive test results, and positivity rates, are influenced by the proportion of the population that is tested and the sampled population.
- Policy statements and decisions should not be based upon a single measure, such as the positivity rate, without taking into account other measures and factors such policies for testing, such as the probability of being tested, the target population for testing, and how these may change over time.

Background

Analysis of testing data, including assessment of changes in positivity rates, has become a routine part of our exploration of the course of the COVID-19 epidemic. However, simple assessments of changes in the numbers of positive test results, and the positivity rates, are influenced by the proportion of the population that is tested and the sampled population (e.g. asymptomatic healthcare workers or patients with clinical manifestations of COVID-19). These may vary in time and space according to testing policies or test-seeking behaviour by the public.

Methods

Variations in the proportion of the total population sampled, and possibly in the sampled population, are illustrated using the data openly available from the Government of Ontario (https://covid-19.ontario.ca/data), Figure 1 shows that:

1. The lowest numbers of tests during a week take place on Tuesdays and higher numbers on Friday or Saturdays. The possible reason is that fewer specimens are collected over the weekends and positive results come 1-2 days after.
2. Lower numbers of testing tend to coincide with higher number of positivity rates and vice versa.
3. Mostly, but not always, higher daily test numbers tend to coincide with higher tested positive numbers (and vice versa).

In addition, the numbers of tests with positive results are not synonymous to the daily number of reported cases (Figure 2), because (i) the positive numbers are “tests” not persons, with possible duplications; and (ii) the daily cases are delayed due to reporting.

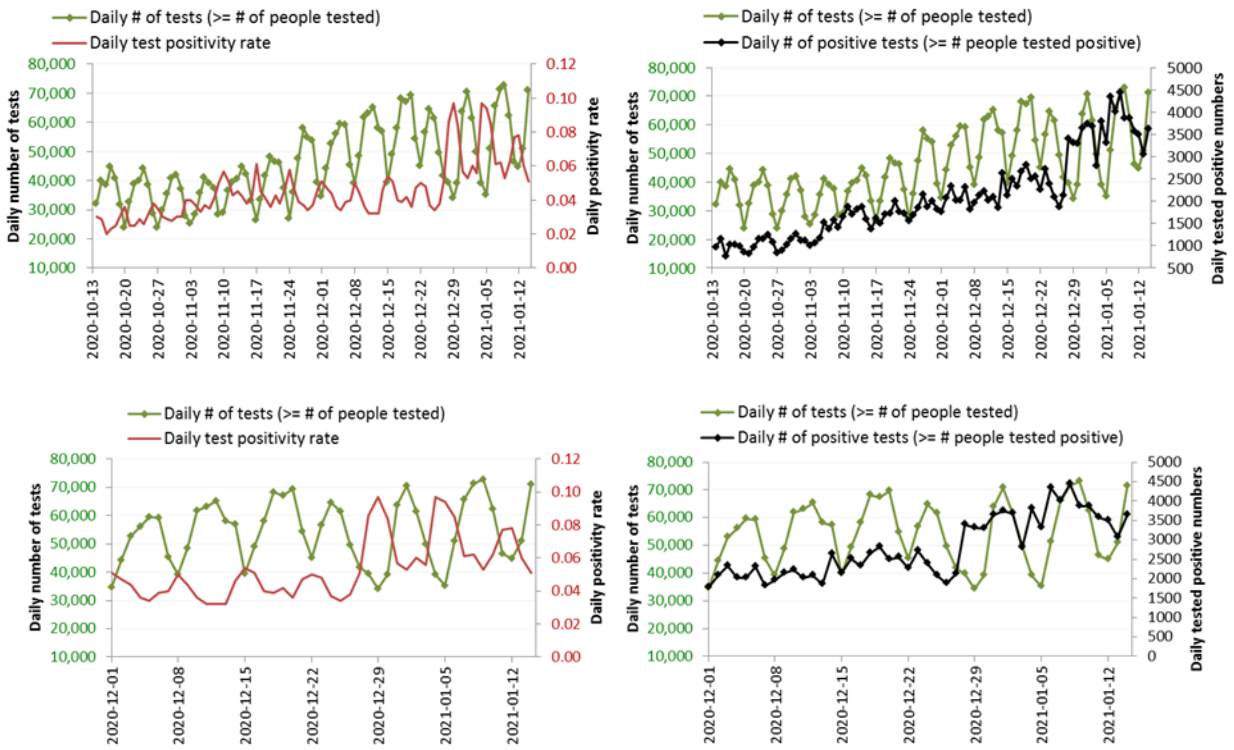


Figure 1. Comparison of the daily number of tests with testing positivity rates (left), and the number of tests with positive results (right). All dates on the x-axis are Tuesdays.

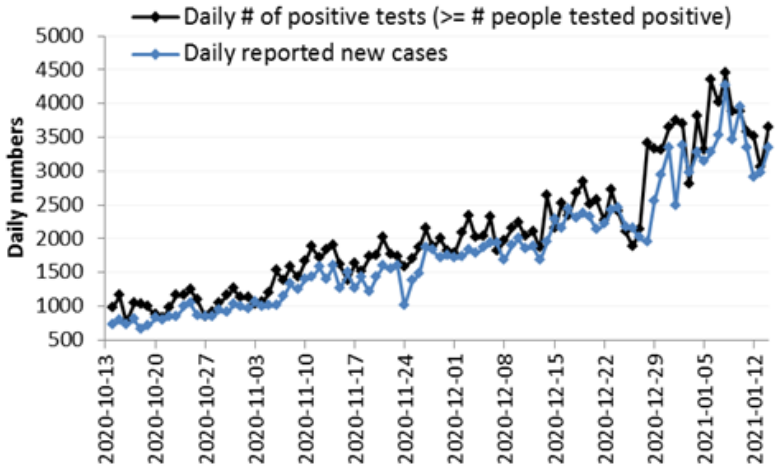


Figure 2. Comparison of the number of tests with positive results with daily reported cases.

To remove the 7-day periodicity, data are aggregated by weeks of the year as shown in Figure 3. There was a sharp increase of the number of tests from Week 45 to Week 51. It did not drive the weekly test positivity rates (PR) downwards, but only forced the PR to stay constant. At the same time, the numbers of positive tests naturally increased at the same rate because the numbers of tests and the numbers of positive tests are proportional. However, this was not the case from Week 42 to 45, or from Week 52 to Week 53.

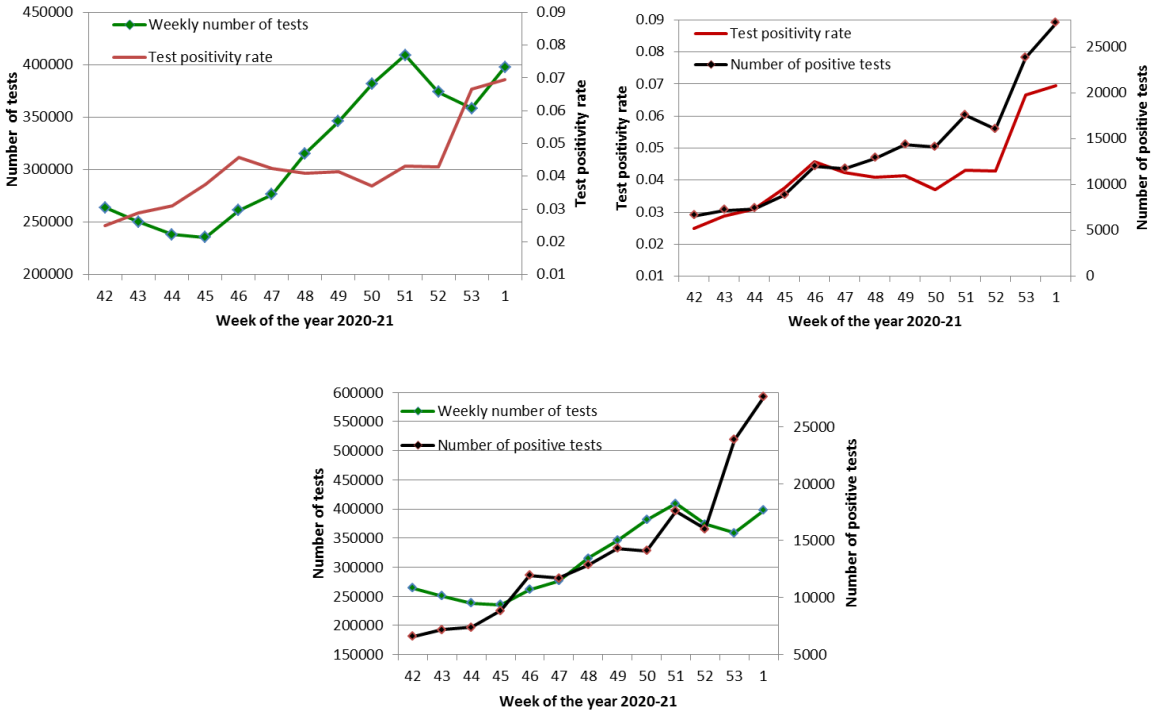


Figure 3. Comparing weekly numbers of tests, positivity rates and numbers of tests with positive results.

In order to understand these relationships, we consider the following 2×2 table:

	Tested	Not tested	Population
positive	C_{test}	?	C_{pop}
negative	$n - C_{test}$	?	$N - C_{pop}$
	n	$N - n$	N

where the observed quantities are:

- $N =$ the total population size;
- $n =$ the number tested in a time period
- $C_{test} =$ the number that tested positive
- $C_{pop} =$ the number of positives in the population in the time period

The key quantity of interest is C_{pop} which is not observable. Another unobserved quantity is the probability that a positive person is tested:

$$\pi = \Pr(tested|positive) = \frac{C_{test}}{C_{pop}}$$

The test positivity rate (PR) is $PR = \frac{C_{test}}{n}$.

An important relationship is

$$C_{test} = n \times PR = \pi \times C_{pop}.$$

1. If the trend of infected individuals in the population C_{pop} remains constant and the probability of seeking testing π also remains constant, then the number of tests n and the positivity rate PR are inversely related, the larger the n the smaller the PR.
    - In Figure 1, the time unit is short (daily) so that the change of C_{test} is relatively small from one day to the next. We see a strong inverse relationship, as the smallest n coincided with the largest PR on Tuesdays during a typical week. When the time unit is larger (e.g. weekly) in Figure 3, the inverse relationship becomes weaker.
2. More testing, n, does not lead to more positive cases, C_{test} , unless PR remains constant.
3. Even if PR remains constant, such as from Week 45 to Week 51, the (increasing) trend of positive tests may not reflect the underlying trend of infected individuals C_{pop} in the population, unless the probability of seeking test among infected individuals π also remains constant.
    - If C_{pop} remains constant, change of C_{test} reflects the change of π, reflecting the change of testing behaviour among the infected people.

For example, we take Week 1 of 2021 (Jan. 4-10) and complete the cells of the 2 x 2 table, assuming that during a 7-period, the probability that the same person gets tested more than once is negligible.

	Tested	**Not tested**	**Population**
positive	27,609	?	?
negative	370,170	?	?
Total	**397,779**	**14,336,235**	**14,734,014**

The above are observable from data. The test positivity rate, PR, is calculated as

$$PR = \frac{C_{test}}{n} \left(= \frac{27609}{397779} = 0.0694\right).$$

Assuming time periods are short enough that very few people are tested more than once,

$$\Pr(tested) = \frac{n}{N}\left(= \frac{397779}{14734014} = 0.027\right).$$

The following quantities are of key interest:

- C_{pop} = The number of infected individuals in the population
- $p = \Pr(infected) = \frac{C_{pop}}{N}$.

We cannot estimate C_{pop} and p unless we make assumptions about $\pi = \frac{C_{test}}{C_{pop}}$, the proportion that is the detected tip of the iceberg of infected people.

The truth lies somewhere between the following two extreme scenarios:

1. Testing is able to capture the whole iceberg, i.e. π =100% . In this case, $C_{pop} = C_{test} = 27609$.

2. Testing arises as a simple random sample. The event "to be tested" is independent of the event "to be infected". In this case, the proportion $\Pr(tested) = \frac{n}{N} = 0.027$ is the same as the proportion C_{test}/C_{pop}. Thus only 2.7% of the infected people get tested which gives $C_{pop} = 1{,}022{,}657$. In this case, $\pi = \Pr(tested) = 0.027$ and $p = PR = 0.0694$.

Assumptions for $0.027 \leq \pi \leq 1$ give the calculations of the following table:

N	n	$\Pr(tested)$	C_{test}	PR	π	p	C_{pop}
14,734,014	**397,779**	**0.027**	**27,609**	**0.0694**	**1.0**	**0.0019**	**27,609**
					0.9	0.0021	30,677
					0.8	0.0023	34,511
					0.7	0.0027	39,441
					0.6	0.0031	46,015
					0.5	0.0037	55,218
					0.4	0.0047	69,023
					0.3	0.0062	92,030
					0.027	**0.0694**	**1,022,657**

Conclusions

- Comparisons of case numbers over time and across jurisdictions should take into account testing levels and how testing is distributed across the population.
- Data provided with test results should be more detailed than is currently the case. In particular, testing and positivity rates should be provided for subgroups or strata in the population, defined according to factors such as age, exposure risk and geographical area.
- Much more could be done on data analysis, so that monitoring and analyzing the course of the pandemic should take into account of all the factors involved (as demonstrated in the 2x2 table).
- Policy statements and decisions should not be based upon a single measure, such as the positivity rate, without taking into account other measures and factors such policies for testing, such as the probability of being tested, the target population for testing, and how these may change over time.

06 ANNEXES

ANNEX 1: PHAC SCENARIOS

Background

Three broad scenarios for the COVID-19 epidemic in Canada over the coming year have been proposed as a basis for planning purposes. These are based on scenarios in the Centre for Infectious Disease Research and Policy (University of Minnesota) CIDRAP Viewpoint of April 30th, 2020 (https://www.cidrap.umn.edu/sites/default/files/public/downloads/cidrap-covid19-viewpoint-part1_0.pdf). These scenarios, and their possible causes are:

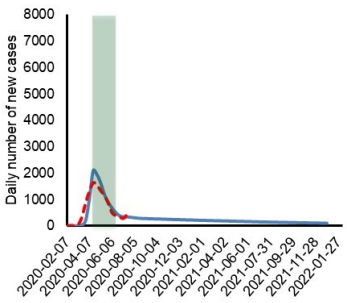
1. "Fall-Winter Peak" – a resurgence of the epidemic in Canada due to alternative public health measures (case detection and isolation, contact tracing and quarantine, and personal distancing) being insufficient to control the epidemic as restrictive closures are lifted.
2. "Peaks and Valleys" – the same as for the "Fall-Winter Peak" but rather than letting the resurgence of the epidemic to continue unchecked, restrictive closures are re-instated to bring it back under control. Subsequent cycles of lifting and re-imposing restrictive closures (without ramping up alternative public health measures) produces the "peaks and valleys."
3. "Slow Burn" –the epidemic in Canada remains under control due to alternative public health measures of case detection and isolation, contact tracing and quarantine, and personal distancing being sufficient to control the epidemic as restrictive closures are lifted.

The scenarios are dimensionless in terms of numbers of cases, hospitalizations and deaths, and the Modelling Group has received multiple internal and external demands for these "scenarios" to be fleshed out in terms of possible case numbers, hospitalizations and deaths, for planning purposes. Modelling Group members have altered models to allow them to recreate these scenarios to produce projected numbers. Using these, we aim to have a limited set of scenarios that are consistent for all internal and external requesters.

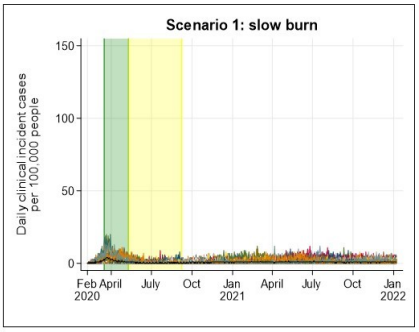
The scenarios and their possible causes

In the following figures, the CIDRAP scenarios are compared with the modelled equivalents. Green bars in the graphs indicate periods when restrictive closures are implemented to control the epidemic. The yellow region in the agent-based model output indicates periods schools are closed beyond the period of implementation of restrictive closures.

Slow Burn: Alternative public health measures maintain control of the epidemic even though imported cases produce occasional outbreaks.

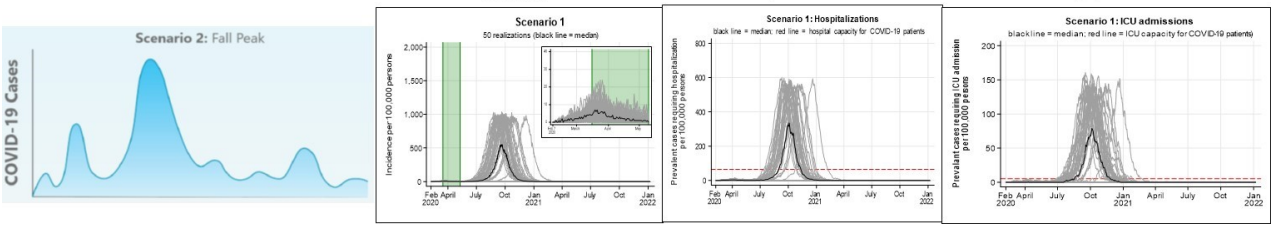


Using deterministic model
Ludwig et al. 2020

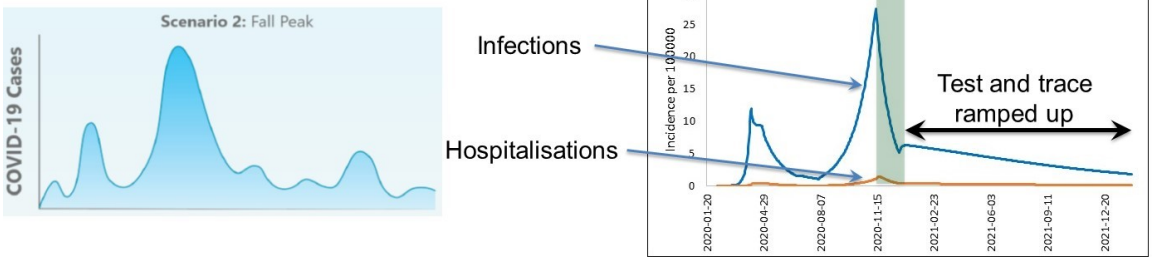


Using agent-based model
Ng et al. 2020

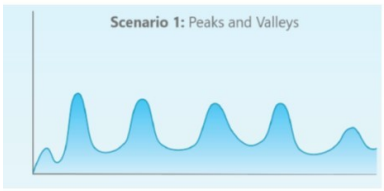
Uncontrolled Fall-Winter Peak: Alternative public health measures are insufficient to control the epidemic, restrictive closures **are not** re-implemented, the epidemic resurges without control, and healthcare capacity is far exceeded.

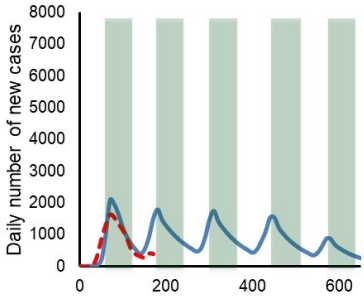


Controlled Fall-Winter Peak: Alternative public health measures are insufficient to control the epidemic, the epidemic resurges but restrictive closures **are** re-implemented to bring the epidemic back under control. Subsequently, alternative public health measures **are** ramped up to control the epidemic as in 'Slow Burn'.

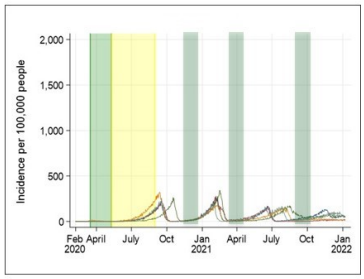


Peaks and Valleys: Alternative public health measures are insufficient to control the epidemic, the epidemic resurges but restrictive closures **are** re-implemented to bring the epidemic back under control. Subsequently, alternative public health measures **are not** ramped up to control the epidemic and the epidemic resurges repeatedly requiring repeated re-implementation of restrictive measures to maintain control of the epidemic.





Using deterministic model
Ludwig et al. 2020



Using agent-based model
Ng et al. 2020

Limitations and use of the scenarios

Limitations of scenarios: These model-derived scenarios are plausible futures that differ due to the degree to which the epidemic is controlled by public health measures and restrictive closures. Serological studies in Canada suggest that the majority of Canadians (>98%) remain naïve to SARS-CoV-2 infection and this is a key assumption in modelling. Because the population remains mostly naïve, the possible number of COVID-19 cases projected in the scenarios, and which we may see in coming months, ranges widely from tens of thousands to millions. All **scenarios** are plausible but **none** should be treated as **forecasts**. The models use parameters, parameter values and assumptions according to our current knowledge of SARS-CoV-2 and its transmission obtained from the literature and data. As this knowledge continues to evolve and change, the scenarios may require updating, and the future epidemic may be different to the scenarios presented here. Even though simulations run until the beginning of 2022, data on numbers of cases etc. are provided up to the end of June 2021 as evolving science and public health interventions, particularly development of therapeutics and vaccines may drastically change the epidemic and the severity of outcomes for affected people.

Use of scenarios: The outputs provided are estimated daily numbers of new infections (i.e. all infections including asymptomatic cases [currently estimated at 38% for the Canadian population in PHAC models according to data in Davies et al. 2020], and detected and undetected clinical cases combined), hospitalizations and deaths per 100,000 population, for each scenario. It is up to the end-user to decide which scenarios to use for each different population in Canada, and it is for the end-user to convert numbers of infections/hospitalisations/deaths into the outcomes that are of most interest to them. Information on the epidemic itself in different parts of Canada may guide selection of scenarios for specific locations. Information for Canada as a whole is available at https://www.canada.ca/en/public-health/services/diseases/coronavirus-disease-covid-19.html, while more local Province/Territory-specific information should be obtained from the websites of those jurisdictions.

Considerations

The data that obtained from modelling are incidence/100,000 population of infections, hospitalizations and deaths. While the models can produce granular estimates of prevalence of hospital and ICU bed occupancy etc. this level of granularity would require a more community-level than country-level approach.

The deterministic compartment model provides a simpler non-stochastic output that is easier to interpret and incorporate into planning calculations. However, the agent-based model provides output that may be more realistic under certain circumstances, including the stochastic nature of how events can actually unfold. The deterministic model does not have the degree of heterogeneity associated with the agent-based model and this

has been associated with estimates of higher case counts. Nevertheless, the degree to which this is higher than what might materialize in reality remains uncertain. For some scenarios, it was considered prudent to calibrate the deterministic model to produce output that has limits identified by simulations of the agent-based model. In any planning application using these scenarios, consideration of additional margins of error relevant to the application would be prudent.

Methods

Scenarios and model selection

Uncontrolled Fall-Winter Peak: This is the "worst case" scenario, and output is obtained from the deterministic model adjusted downwards by 50% according to the output on uncontrolled resurgence in the agent-based model, because the more heterogeneous mixing in the latter may provide a more realistic upper limit.

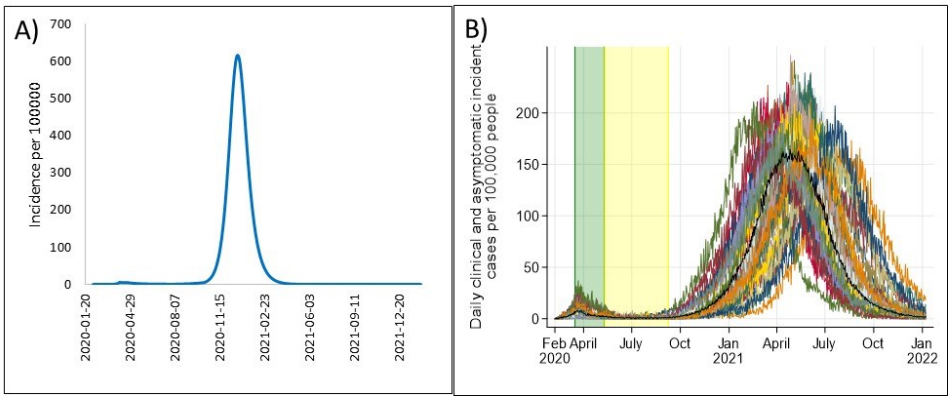


Figure 1. The uncontrolled Fall-Winter Peak simulated by the deterministic model (A) and the agent-based model (B). In this and other figures showing agent-based model output, the green and yellow vertical bars in (B) correspond, respectively, to the periods of restrictive closures and school closures, the black line shows the median value of 50 simulations, while the coloured lines show the output of individual simulations. The heterogeneous mixing in the agent-based model results in a longer curve with a lower peak incidence.

Controlled Fall-Winter Peak: Output is obtained from the deterministic model with two versions – one with an early implementation of enhanced public health measures, and one with late implementation.

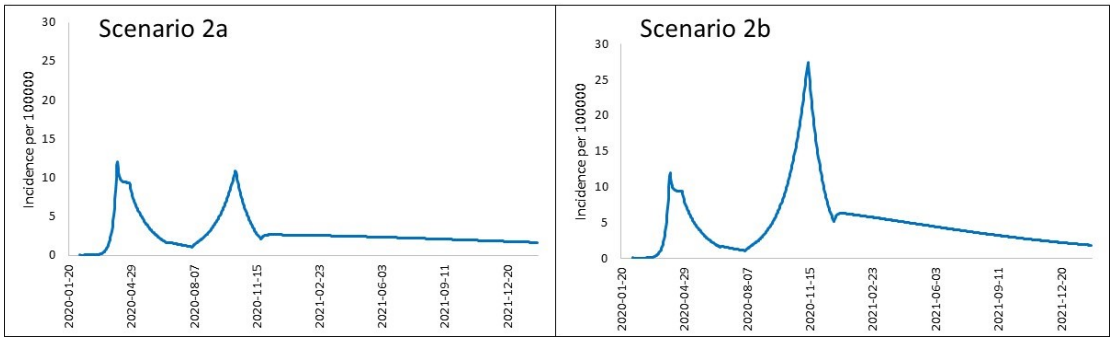


Figure 2. Two different scenarios for a controlled Fall-Winter Peak simulated using the deterministic model. Control of the Fall-Winter peak is implement early in Scenario 2a, and later in Scenario 2b.

Peaks and Valleys: The agent-based model was used to capture the variability in onset of peaks and valleys in different locations. Two versions were obtained - one with high peaks, one with lower peaks similar to current peaks.

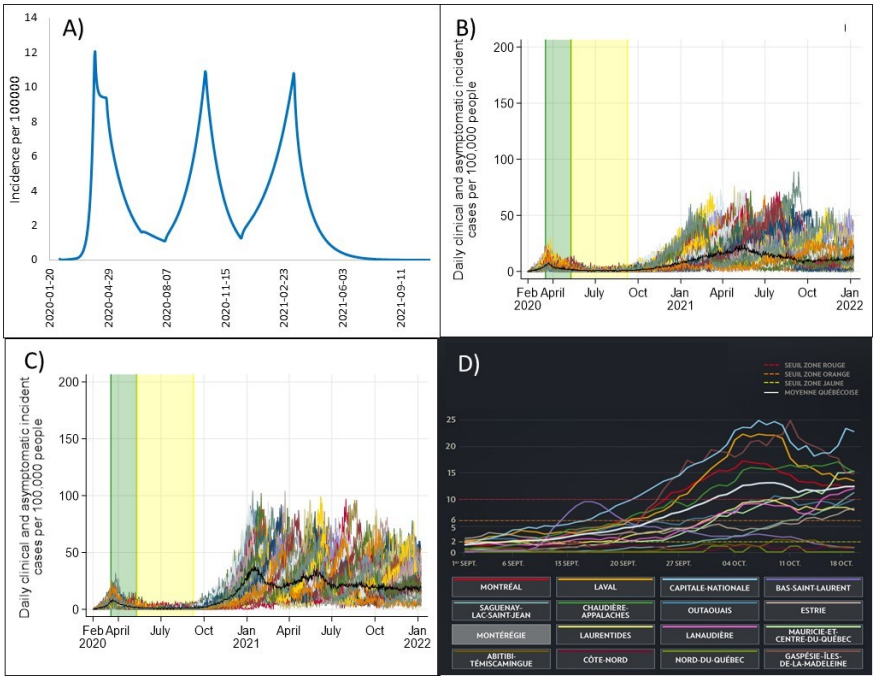


Figure 3. Peaks and Valleys scenarios simulated by the deterministic model (A) and the agent-based model using two scenarios producing low peaks (B) and high peaks (C). Mean output from the agent-based model was used in producing numbers of infections, as it is more consistent with the temporally varying patterns of resurgence and control in different parts of affected provinces such as Quebec (D, from LaPresse 2020-10-21).

Slow Burn: Agent-based model output was used to better account for transmission from imported cases. Slow Burn is the "best case" scenario.

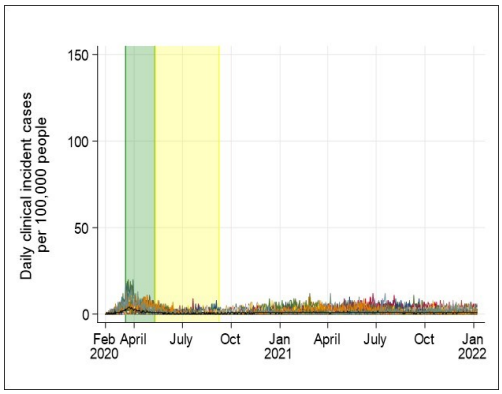


Figure 4. The Slow Burn scenario simulated by the agent-based model.

Model parameters

Deterministic model methods: The simulations were run using the SEIR deterministic model (Ludwig et al. 2020). All simulated epidemic used the same parameter values up until day 248 (Oct 12th) upon which significant changes in the level of physical contact were implemented to simulate full release of restrictive closures. Before day 248, the parameters were calibrated on surveillance data of identified and hospitalized cases in Canada to represent the first spring peak. It should be noted that multiple parameters are involved and that alternative, slightly different combinations of parameter values could have resulted in a similar fit. After day 248, the level of contact over time, the level of case detection/isolation as well as the level of contact tracing were modified as in Table 1.

Table 1. Scenarios of the deterministic model

Scenario	Sub scenario	Description of the scenario
Uncontrolled peak	1	Until the end of the epidemic, contact rates maintained at 80% of the pre-epidemic level; contact tracing and case identification/isolation are maintained at 50%. Note that output was set at 50% of the simulation results according to upper 97.5 percentile of an uncontrolled peak modelled using homogenous mixing with the agent-based model.
Controlled fall peak	2a -early control	Intervention starts early (on day 248) with contact rates reduced to 40% pre-pandemic levels for 40 days, and case identification and contact tracing increased to 70%. Following the 40 day period, physical distancing is relaxed increasing contact rates to 70% of the pre-epidemic level while case identification and contact tracing are maintained at 70%
Controlled fall peak	2b -late control	Intervention starts late (on day 279) with contact rates reduced to 40% pre-pandemic levels for 40 days, and case identification and contact tracing increased to 70%. Following the 40 day period, physical distancing is relaxed increasing contact rates to 70% of the pre-epidemic level while case identification and contact tracing are maintained at 70%

Agent-based model: The simulations were run using the agent-based model of Ng et al. (2020). Output used for scenarios is the mean for 50 simulations for each scenario. The conditions used for these scenarios are presented in Table 2. In each case imported cases from international locations at current estimated rates are included.

Table 2. Scenarios of the agent-based model

Scenario	Sub scenario	Description of the scenario
Uncontrolled peak	1	Case detection and isolation compliance increases from 20% (day 0) to 40% (day 94) and remains at 40% 50% of household members also co-isolate with sick household members Contact tracing and quarantine compliance remains as 50% of detected cases throughout the model run Physical distancing varies from 20% reduction in contact rate (day 38) to 50% reduction (day 94) to 40% reduction (day 129) to 30% reduction (day 159) and 10% reduction for the remaining model run (day 190)

		Physical distancing varies from 20% reduction in contact rate (day 38) to 50% reduction (day 94) to 40% Initial shutdown occurs from March 16 to May 10 (green bar). Shutdown consists of 100% of schools, 40% of workplaces (mostly teleworkers) and 50% of mixed age venues (non-essential businesses). Shutdowns are modelled on the decline in mobility observed from March to May using
Peaks and Valleys	3a – low peaks	Case detection and isolation compliance increases from 20% (day 0) to 40% (day 94) and remains at 40% 50% of household members also co-isolate with sick household members Contact tracing and quarantine compliance remains as 50% of detected cases throughout the model run Physical distancing varies from 20% reduction in contact rate (day 38) to 50% reduction (day 94) to 40% reduction (day 129) to 30% reduction (day 159) and 20% reduction for the remaining model run (day 190) Physical distancing varies from 20% reduction in contact rate (day 38) to 50% reduction (day 94) to 40% Initial shutdown occurs from March 16 to May 10 (green bar). Shutdown consists of 100% of schools, 40% of workplaces (mostly teleworkers) and 50% of mixed age venues (non-essential businesses). Shutdowns are modelled on the decline in mobility observed from March to May using Google mobility data After initial shutdown, schools remained close and individuals continued to telework until Sep 7 (day 213) and. On day 214, schools reopened and we assume everyone returns to work.
Peaks and Valleys	3b – high peaks	Case detection and isolation compliance increases from 20% (day 0) to 40% (day 94) and remains at 40% 50% of household members also co-isolate with sick household members Contact tracing and quarantine compliance remains as 50% of detected cases throughout the model run Physical distancing varies from 20% reduction in contact rate (day 38) to 50% reduction (day 94) to 40% reduction (day 129) to 30% reduction (day 159) and 10% reduction for the remaining model run (day 190) Physical distancing varies from 20% reduction in contact rate (day 38) to 50% reduction (day 94) to 40% Initial shutdown occurs from March 16 to May 10 (green bar). Shutdown consists of 100% of schools, 40% of workplaces (mostly teleworkers) and 50% of mixed age venues (non-essential businesses). Shutdowns are modelled on the decline in mobility observed from March to May using Google mobility data After initial shutdown, schools remained close and individuals continued to telework until Sep 7 (day 213) and. On day 214, schools reopened and we assume everyone returns to work.

Slow burn	4	Case detection and isolation compliance increases from 20% (day 0) to 40% (day 94) and remains at 40% 50% of household members also co-isolate with sick household members Contact tracing and quarantine compliance remains as 50% of detected cases throughout the model run Physical distancing varies from 20% reduction in contact rate (day 38) to 50% reduction (day 94) to 40% reduction (day 129) to 20% reduction (day 159) and 40% reduction for the remaining model run (day 190) - not a typo, we assume people were a bit more relax over the summer but gets it together moving forward Initial shutdown occurs from March 16 to May 10 (green bar). Shutdown consists of 100% of schools, 40% of workplaces (mostly teleworkers) and 50% of mixed age venues (non-essential businesses). Shutdowns are modelled on the decline in mobility observed from March to May using Google mobility data After initial shutdown, schools remained closed and individuals continued to telework until Sep 7 (day 213) and. On day 214, schools reopened and we assume everyone returns to work

Results

Outputs for requesters of scenarios will include this guidance information, which includes summaries of infections, hospitalizations and deaths for each scenario (Table 3), as well as an Excel spreadsheet containing the daily data in the scenarios from that is available on request. The latter comprises data from the agent-based model that has been smoothed using rolling averages to reduce daily variations associated with the stochastic elements of the model.

Table 3. Summary statistics for each scenario from October 1st, 2020 up to June 30th, 2021. Numbers are totals for this period per 100,000 population. "Cases" includes all infections. Note that due to the stochastic nature of the agent-based model, precise values in this table may differ slightly from those calculated simply from smoothed values presented in the Excel spreadsheets.

Scenario	Model	Infections	Hospitalizations	Deaths
Uncontrolled Fall-Winter Peak	Deterministic*	32,976	1,819	611
Controlled Fall-Winter Peak scenario 2a	Deterministic	878	53	14
Controlled Fall-Winter Peak scenario 2b	Deterministic	2,221	126	34
Peaks and Valleys – low peaks	Agent-based	3,777	224	31
Peaks and Valleys – high peaks	Agent-based	6,445	382	59
Slow Burn	Agent-based	569	38	6

* Adjusted according to output from the agent-based model.

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Ludwig A, Berthiaume P, Orpana H, Nadeau C, Diasparra M, Barnes J, Hennessy D, Otten A, Ogden N. 2020 Assessing the impact of varying levels of case detection and contact tracing on COVID-19 transmission in Canada during lifting of restrictive closures using a dynamic compartmental model. Can Commun Dis Rep 46, 409–21

Ng V, Fazil A, Waddell LA, Bancej C, Turgeon P, Otten A, Atchessi N, Ogden NH. 2020. An agent-based model of COVID-19 transmission in Canada: forecasting impacts of non-pharmaceutical public health interventions. CMAJ 192, E1053-E1064

ANNEX 2: METHODS USED AND QUALIFYING STATEMENTS

Empirical model methods

The Generalized Richards Model (GRM) was used at this stage of the pandemic to project future cases and deaths in the near-term. This model can capture the possibility of early sub-exponential growth epidemics (ranging from constant incidence, polynomial, and exponential growth dynamics). It generally fits a wide range of S-shaped growth curves, more so than the logistic model due to its accommodation of situations where the growth curve is asymmetrical (e.g. (http://currents.plos.org/outbreaks/article/usingphenomenological-models-to-characterizetransmissibility-and-forecast-patterns-and-final-burdenof-zika-epidemics/).

Limitations

The models used for near-term forecasting do not explicitly consider the mechanisms of transmission of COVID-19, including human behaviours and response to the epidemic. Future growth of the epidemic is entirely based on historic reported case counts. As such, these models do not explicitly consider the impacts of recently implemented or de-escalation of mitigation measures (social distancing, facility closures, etc), and the effects of such measures do not influence projections until actually observed in the reported surveillance case data. The models also do not account for any delays in testing, testing backlogs, changes to number of tests performed daily, or changes to testing eligibility, etc.

Importation risk model

Model structure

The model is organised into five parts: a) air and land travel volumes, b) country-specific weekly incidence rate, c) underreporting correction factor, d) temporal infection dynamics, and e) calculation of the number of passengers arriving infected in Canada.

Air and land travel volumes

Current daily travel volumes expected into Canada are provided by the Canadian Border Services Agency (CBSA) from advanced passenger information (API). These data provide the most up-to-date source of expected travel volumes to Canada, but are limited by not being the actual count of arriving passengers (an issue if some passengers decided not to fly at the last minute), plus some airlines do not contribute to the API. Furthermore, the departure location is only defined for the last leg of travel, thus, the starting country for multiple leg trips is unknown. Travel volumes for air travel at the itinerary level are provided from the International Air Transport Authority (IATA). CBSA and IATA data have daily and monthly resolutions, respectively. Furthermore, the IATA data are received with a 60-day delay. Therefore, to calculate importation risk at the PoE level in Canada for air travellers, the country arrival total from CBSA is distributed in proportion to airport totals reported by IATA.

Country-specific weekly incidence rate

Weekly incidence rate $\gamma_{c,w}$ at the country level *c* for epi-week *w* is a product of new infections during that week, $N_{c,w}$, and the inverse of the population at risk, which we will assume to be equal to the country population size, p_c, for 2019[3] as:

$$\gamma_{c,w} = \frac{N_{c,w}}{p_c} \quad (1)$$

The number of new cases $N_{c,w}$ during week *w* is calculated by subtracting the cumulative reported cases *I* at week *w-1* from the cumulative reported cases on week *w*, multiplied by a factor α_c which corrects for underreporting in country *c*:

$$N_{c,w} = \alpha_c\left(I_{c,w} - I_{c,w-1}\right) \quad (2)$$

We used a weekly incidence rate rather than a daily incidence rate since confirmed cases are not reported consistently on a daily basis in every country.

Underreporting correction factor

The number of confirmed cases reported from national surveillance systems underestimates the true population prevalence because of inadequacies in the healthcare system to detect, test and report cases, including lower probability of observing asymptomatic cases. For the purpose of this model, the underreporting correction factor, α_c, was inferred from serological studies. SeroTracker[4] is an open-source web resource reporting results from SARS-CoV-2 serosurveys globally. Studies included in the derivation of α_c conformed to the following criteria:

1) National-level study
2) Risk of bias in results was low or moderate as based on the Joanna Briggs Institute Critical Appraisal Guidelines for Prevalence studies
3) Type of people sampled were considered representative of the general population (i.e. household and community samples, blood donors, residual sera from non-COVID-19 investigations, students, non-essential workers and unemployed persons, pregnant or parturient women, and patients seeking care for non-COVID-19 reasons)

An alpha value was calculated for each selected seroprevalence study by dividing the mean seroprevalence estimate with the mean prevalence estimated from the corresponding national surveillance data reported for the same time period. For countries with more than one selected seroprevalence study, the alpha value for that country was the mean of the multiple values. From access to SeroTracker data as of December 30th, 2020, this approach resulted in alpha values for 17 countries. Therefore, to estimate alpha values for the other countries a regression modelling approach was used to regress the alpha value (dependent variable) on country-specific predictors: a) Detection and Reporting score (DRS) from the 2019 Global Health Security index[5] as a measure of the capacity of the country to detect and report infectious disease cases, and b) the 2019 Growth National Income

[3] Data source: United Nations Department of Economic and Social Affairs

[4] Accessible at: serotracker.com
Bobrovitz et al. Lessons from a rapid systematic review of early SARS-CoV-2 serosurveys. medRxiv 2020.05.10.20097451; doi: https://doi.org/10.1101/2020.05.10.20097451

[5] https://www.ghsindex.org/

(GNI) per capita[6] as a proxy for the effectiveness of the surveillance system to detect, test and report COVID-19 cases. We derived the functional form of the variables with the response variable and verified that they did not violate model assumptions of linearity. The correlation between DRS and GNI was considered too high to include in the same multivariable model (Pearson's r ≥ 0.4). The best model was selected as having the lowest value for the Akaike's information criterion (AIC) and residuals that conformed to the parametric distribution. The predictor in the final model was a log-transformed value of GNI per capita. This model was used to impute the alpha value for countries without seroprevalence data, as per our aforementioned criteria.

Temporal infection dynamics

The daily incidence rate is converted into the daily mean probability β of an individual from country *c* becoming infected on a given day of week *w*:

$$\beta_{c,d} = 1 - e^{-\frac{\Upsilon_{c,w}}{7}} \quad (3)$$

Similarly, the daily mean probability β of an individual from Canada (home country) becoming infected in Canada on a given day of week *w is*:

$$\beta_{h,d} = 1 - e^{-\frac{\Upsilon_{h,w}}{7}} \quad (4)$$

The probability of a traveller importing infection into Canada from country *c* depends in part on whether they have already been exposed, infected and recovered from COVID-19 since the start of the pandemic. To simplify the modelling approach, we define the start of the pandemic as January 1st 2020 and assume that recovered individuals become permanently immune. Also we assume there are two types of travellers. Canadian residents, CR, spend all their time in Canada since the start of the pandemic except for a visit of t_c days to country *c* where infection can occur and cause importation risk. The second type of traveller is called a foreign national, FN. These travellers are assumed to have spent all their time in country *c* since the start of the pandemic and then visit Canada and contribute to importation risk. The value of t_c for CRs is described by a normal distribution $N(15, 2)$ under the assumption that most CRs have approximately 15 days of annual leave to spend in country *c*[7]. For FNs t_c is the time from the start of the pandemic to date.

The model estimates the number of infected CRs and FNs coming to Canada for a given week *w*. Infection is imported when a person travelling to Canada gets infected in country *c* on any day during the last $n - 1$ days prior to departure given that the person is not yet immune. Here *n* is the sum of the latent and infectious periods, described by normal distributions N(3.5, 1.0) and N(12, 4.0) days, respectively[8].

[6] The World Bank, World Development Indicators (2019). *GNI per capita, Atlas method* [Data file]. Retrieved from https://data.worldbank.org/indicator/NY.GNP.PCAP.CD

[7] Data source: Messenger JC, Lee S, McCann D. Working time around the world: Trends in working hours, laws, and policies in a global comparative perspective. 1st ed. London: Routledge; 2007.

[8] https://www.sciencedirect.com/science/article/pii/S1198743X20302317; https://www.sciencedirect.com/science/article/pii/S2352396420302917; https://www.sciencedirect.com/science/article/pii/S0196655320306441?via%3Dihub

For the purpose of the below analyses, we will assume that day 0 is January 1st, and that day *s* is the day at which the individual is travelling from country *c* to Canada (i.e. *s* is the number of days between the start of the pandemic and the travel date to Canada).

FN infection probability:

The probability of not being infected in country *c* during the entire t_c period is $\prod_{d=s-t_c}^{s}(1-\beta_{c,d})$

For FNs, when $t_c < n-1$, the probability of an individual travelling by air from country *c* to arrive at their final destination in Canada on day *s* infected is:

$$P_{c,s}^{FN} = 1 - \prod_{d=s-t_c}^{s}(1-\beta_{c,d}) \tag{5}$$

When time in country *c* becomes larger than the sum of latent and infectious periods (i.e. $t_c \geq n-1$), the probability of a visitor not entering Canada infected is calculated as the sum of the probability of not getting infected during t_c and the probability of getting infected, recovering and becoming immune before departure. Therefore, the probability of an individual travelling by air from country *c* to arrive at their final destination on day *s* infected is:

$$P_{c,s}^{FN} = 1 - \left[\prod_{d=s-t_c}^{s}(1-\beta_{c,d}) + \left(1 - \prod_{d=s-t_c}^{s-(n-1)}(1-\beta_{c,d})\right)\right] \tag{6}$$

$$P_{c,s}^{FN} = \prod_{d=s-t_c}^{s-(n-1)}(1-\beta_{c,d}) - \prod_{d=s-t_c}^{s}(1-\beta_{c,d}) \tag{7}$$

CR infection probabilities:

We assume that a person that has become infected in Canada at any point since the start of the pandemic to the date of departure from Canada to country *c* cannot import infection from country *c*, as they will have developed immunity against infection. The duration of time for which immunity may have developed from an infection in Canada is $t_h = s - t_c$, where *s* is the number of days since the start of the pandemic.

For CRs who have a visit to country *c* that is less than $n-1$, (i.e. $t_c < n-1$), the probability of a CR importing infection from country *c* into Canada on day *s* is equal to the probability of getting infected on any day during t_c, given that the person did not get infected in Canada on any day before the trip:

$$P_{c,s}^{CR} = \left(1 - \prod_{d=s-t_c}^{s}(1-\beta_{c,d})\right) * \prod_{d=0}^{t_h}(1-\beta_{h,d}) \tag{8}$$

When the length of stay is longer, that is $t_c \geq n-1$, the probability of not being infected in country *c* is the sum of the probability of not getting infected during t_c and the probability of being infecting (i.e. infected, recovered and immune in Canada before visiting country c). Therefore, for CRs who have a visit to country *c* that is $t_c \geq n-1$, the probability of a CR importing infection from country *c* into Canada on day *s* is:

$$P_{c,s}^{FN} = \left(1 - \left[\prod_{d=s-t_c}^{s}\left(1-\beta_{c,d}\right) + \left(1 - \prod_{d=s-t_c}^{s-(n-1)}\left(1-\beta_{c,d}\right)\right)\right]\right) * \prod_{d=0}^{t_h}\left(1-\beta_{h,d}\right) \quad (9)$$

$$P_{c,s}^{FN} = \left(\prod_{d=s-t_c}^{s-(n-1)}\left(1-\beta_{c,d}\right) - \prod_{d=s-t_c}^{s}\left(1-\beta_{c,d}\right)\right) * \prod_{d=0}^{t_h}\left(1-\beta_{h,d}\right) \quad (10)$$

Calculating the number of passengers arriving infected in Canada

The mean number of travellers departing from country *c* arriving infected at port of entry *k* on day *s* is:

$$I_{k,s} = \sum_{i,c} v_{i,k,s}\left[qP_{c,s}^{CR} + (1-q)P_{c,s}^{FN}\right] \quad (11)$$

where $v_{i,k,s}$ is the volume of passengers on day *s* departing from country *c* in airport *i* and arriving in Canada at port of entry *k*, when through air travel. Also, *q* is the proportion of Canadian residents compared the number of visitors departing from country *c* to visit Canada. The model calculates the daily probabilities of introduction for CRs and FNs departing from each country at each of the seven days of a given epi-week. The daily number of travellers infected are calculated for each day and summed over the given epi-week.

Symptomatic people are not allowed to travel, but also, some people that become symptomatic will travel during their incubation period when no symptoms are presenting. Therefore, the estimate of infected travellers $I_{k,s}$ is adjusted to those that are assumed to be asymptomatic, or in their incubation period as follows:

$$I_{k,s}^{*} = I_{k,s} \times P_{inc} + I_{k,s}(1 - P_{inc}) \times \theta \quad (12)$$

where the probability a person is incubating, P_{inc}, is the (mean incubation period) / (mean incubation period + mean symptomatic period). The mean incubation period is assumed to be 6 days[9] and the mean symptomatic period is assumed to be 14 days[10] given many people fully recover within 14 to 21 days of symptom onset. The probability of developing an asymptomatic infection, θ, is assumed to be 0.30 given that asymptomatic transmission is estimated to range from 15 to 45%[11].

[9] http://dx.doi.org/10.1136/bmjopen-2020-039652;
https://doi.org/10.1016/j.rceng.2020.08.002
[10] doi:10.1017/ice.2020.1334;
http://dx.doi.org/10.15585/mmwr.mm6930e1
[11] https://doi.org/10.21203/rs.3.rs-126538/v1;
https://doi.org/10.1371/journal.pmed.1003346;

Model assumptions

- Canadian residents and visitors to Canada experience the same rates of exposure (i.e. $\beta_{c,t}$) while in the departure country
- Probability of a person being in their incubation period at time of travel is 0.3
- Probability of being asymptomatic following the incubation period is 0.3
- Infected travellers do not spread infection during travel
- Susceptible travellers do not get exposed to COVID-19 during travel by non-travellers (e.g. airport service employees)
- Immunity is permanent
- Country-specific underreporting correction factors do not vary with time

Model limitations

- The model does not account for the right-truncation of reported cases, in that there is underreporting in the most recent days because of infected people that yet to develop symptoms and seek testing
- Underdevelopment is to account for the new travel policy enacted on January 7th 2021 to have a negative COVID-19 test result 1-3 days prior to departure to Canada

Agent based model methods

An agent-based model has been developed at PHAC to simulate the potential spread of COVID-19 in small to mid-sized communities in Canada (1,000 to 100,000). Agents move through progressive disease states. The model is stochastic and parameterised using scientific information of COVID-19 from the literature with a Canadian context in mind (i.e. number of contacts, testing delay). Stochasticity in the model allows for a range of outputs that provides an estimation of the most likely values, as well as the lower and upper bound values. The model has been developed to explore NPI for COVID-19 transmission in Canada. Full details of the model are available at: https://www.cmaj.ca/content/early/2020/08/19/cmaj.200990.2

Reference:

Ng V, Fazil A, Waddell LA, Bancej C, Turgeon P, Otten A, Atchessi N, Ogden NH. Projected effects of nonpharmaceutical public health interventions to prevent resurgence of SARS-CoV-2 transmission in Canada. CMAJ. 2020 Aug 9:cmaj.200990. doi: 10.1503/cmaj.200990. Online ahead of print.

R compartment model methods

We developed an updated version (v15) of the age-stratified dynamic deterministic compartmental model using the susceptible, exposed, infected, removed (SEIR) framework applied to the Canadian population stratified into six age groups, as presented in Ludwig et al. 2020. Model states are presented in the figure below.

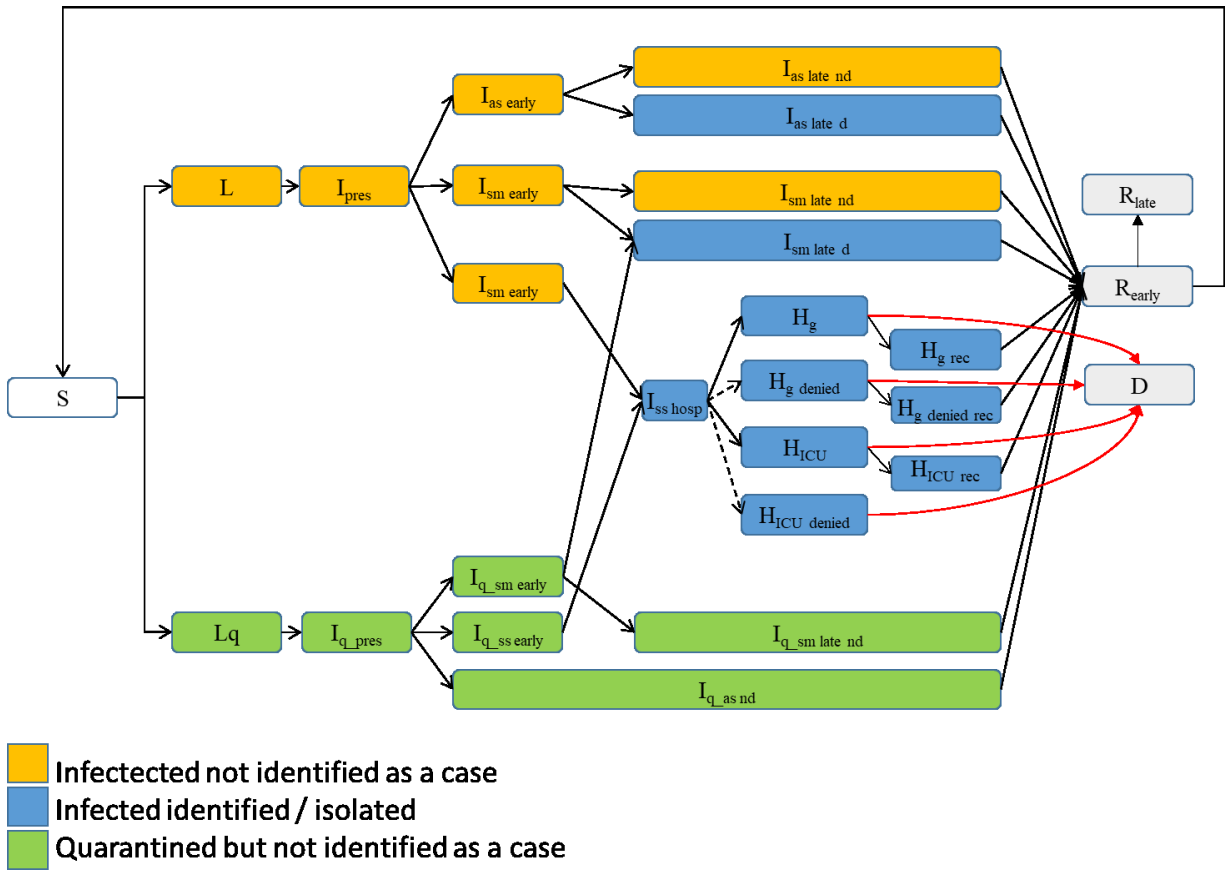

Figure 1. Conceptual flow model of PHAC SEIR age stratified model v15

Transmission between individuals can occur within or between age groups at rates influenced by the daily contact number, based on the matrix projected for Canada by Prem et al (2017). Individuals in quarantine were assumed to interact with a maximum of one person daily during the course of the quarantine. As the model aims to explore the epidemic over a short time period (730 days), the model has a closed population with no births and nonCOVID-19 related deaths, with a population comprising susceptible people at the beginning of the epidemic. Cases who recover are not susceptible to re-infection during the time period of the simulation (730 days). It also assumes the infectivity of pre-symptomatic infectious individuals who become symptomatic is the same as that of symptomatic individuals as well as individuals who remain asymptomatic throughout the course of infection. We assume there is a one to 4 days delay between the hypothetical onset of symptoms (after presymptomatic period) and case detection and isolation. We assume that all detected cases will go into isolation. We consider that the first

community transmission of COVID-19 in Canada was Feb 7th. The simulations were run for the entire Canadian population, stratified in six age groups. Initial states values for the epidemics were set according to the number of cases, as well as the number of hospitalized cases reported in Canada.

Model parameters were adjusted by comparing the number of cases and number of hospitalizations to observed data, until day 283 of the epidemic (Nov 16th). The observed data for cases used for model comparison are publically available surveillance data reported daily from the provinces to PHAC (https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection.html). The observed data for hospitalization are the data reported by provinces to PHAC and available through our internal drive (\\Ncr-a-phacc1s\phacc1\HPOC\Active Events\001-20 COVID-19\Dashboard). The observed data were smoothed over a 7 day period to mimic daily variations in reporting related to day of the week.

Until day 283, model parameters were kept constant, and consistent with the value available in the tables below, except for beta, lambda, time to testing and delta, that were allowed to vary between a certain range to allow the search of the best fit between the simulation and the observed data. Time until day 283 were split into regular periods to match with epidemic curve behavior. A 'goodness of fit' (GOF) statistics was calculated for each time period, and corresponded to the difference between observed and predicted detected cases and hospitalized cases at the end of each time period. For each time period, 2000 simulations were run and the parameter combinations corresponding to the lowest GOF was retained. Additional manual adjustments of parameter values was performed to improve visual model fit.

The figure below represents the evolution of the cumulative number of detected cases and hospitalizations through time provided by surveillance data and model simulations.

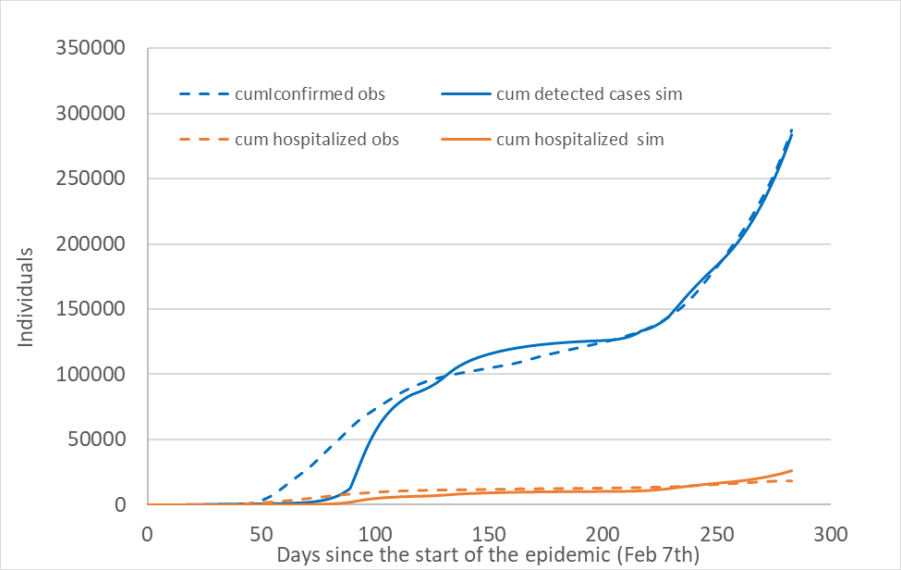

Figure 2. comparison of model prediction (v15) to observed data. Blue curves correspond to detected cases (plain line are simulations and dotted lines are observations). Orange curve correspond to hospitalizations (plain line are simulations and dotted lines are observations).

Generally, the model simulations fit well visually to observed data for cases and hospitalization until Nov 16th. The fit is less good during the first epidemic wave (spring 2020) but the model's predictions end up reconciling the observed data.

A modification in hospitalisation dynamics seems to occur starting around day 260 (end of August) making the fit between model prediction and overserved data less accurate for hospitalizations. Change in hospitalization and the fit of the model to this change will be explored when data are available for a longer period of time.

Table 1. Model compartment descriptions:

State	Definitions	Initial values (blanks means zero)
S	Susceptible	Stratification by age group, StatCan Population estimates July 1. 2019 [37] [0,10) 3982527 [10,20) 4146397 [20,40) 10286131 [40,60) 10069708 [60,75) 6315255 75+ 2789244
Lq	Latent in quarantine	
L	Latent in the general population (not in quarantine)	10
I_pres	Infected pre-symptomatic in the general population (and first infectious period for asymptomatic)	20
Iq_pres	Infected pre-symptomatic in quarantine (and first infectious period for asymptomatic)	
Iq_as_nd	Infected in quarantine not detected (asympt) after the first phase of the infectious period until end of quarantine	
Iq_sm_early	Infected in quarantine with mild symptoms after the presymptomatic infectious period and before detection	
Iq_ss_early	Infected in quarantine with severe symptoms after the presymptomatic infectious period and before detection	
Iq_sm_late_nd	Non-detected Infected in quarantine with mild symptoms in the late phase of infectious period	
I_as_early	Infected non-detected in the general population with no symptoms between end of theoretical presymptomatic infectious period and detection	
I_sm_early	Infected non-detected in the general population with mild symptoms between end of presymptomatic infectious period and detection	
I_ss_early	Infected non-detected in the general population with severe symptoms between end of presymptomatic infectious period and detection	
I_as_late_nd	Infected in the general population that keeps being asymptomatic after possible detection time and are not detected	
I_as_late_d	Detected infected in the general population that keeps being asymptomatic after detection	
I_sm_late_nd	Infected in the general population that have mild symptoms and are not detected even after detection time	

I_sm_late_d	Detected infected in the general population that have mild symptoms	
Iss_hosp	Detected infected with severe symptoms, after early phase of infection, who are in hospital sorting	
H_g_OK	Infected with severe symptoms who stay at the hospital in the general care service during the first phase of hospital stay	
H_g_rec	Infected with severe symptoms who stay at the hospital in the general care service during the second phase of hospital stay	
H_ICU_OK	Infected with severe symptoms who stay at the hospital in ICU during the first phase of hospital stay	
H_ICU_rec	Infected with severe symptoms who stay at the hospital in ICU during the second phase of hospital stay	
H_g_denied	Infectious with severe symptoms who are not able to access hospital care because of insufficient/overwhelmed local capacity during the first phase of hospital stay	
H_g_denied_rec	Infectious with severe symptoms who are not able to access hospital care because of insufficient/overwhelmed local capacity during the second phase of hospital stay	
H_ICU_denied	Infectious with severe symptoms who are not able to access ICU because of insufficient/overwhelmed local capacity	
R_early	Recovered after infection	
R_late	Recovered who keep been immune	
D	Dead	

Table 2. Model parameters:

Parameter name	**Definition**	**Value**	**Evidence**
beta	probability of transmission when contact made with infectious person	[0,10) 0.041 [10,20) 0.041 [20,40) 0.041 [40,60) 0.041 [60,75) 0.041 75+ 0.041	Based on Stilianakis et al [38] and adjusted using data from the beginning of the epidemic (Fig. 2)
lambda	proportion of exposed to detected infectious who are traced and quarantined (contact tracing/quarantine)	Adjustment according to observed data for historical part	
c_{gg}	number of daily contacts between two individuals from the general population	6*6 matrix Values in Ludwig et al, 2020 Adjustment according to historical data for historical part	Based on Prem et a, 2017

c_{gq}	number of daily contacts between an individual from the general population and an individual from the quarantined population	6*6 matrix identical during all the duration of the simulation Values in Ludwig et al, 2020	We assumed a person in quarantine is in contact with a maximum of 1 person each day during his/her quarantine period. The value of one was then standardised according to the total population size in each strata.
sigma	latent period (days)	4.12 days	Based on Li et al (2020), Pei & Shaman (2020), and Maslov & Goldenfeld (2020) [39–41]
delta	proportion of early a- or symptomatic infectious who will be identified (or detected).	Adjustment according to historical data for historical part Age-stratified	
alpha	proportion of symptomatic infected who develop severe symptoms	[0,10) 0.0086 [10,20) 0.0091 [20,40) 0.0179 [40,60) 0.0512 [60,75) 0.167 75+ 0.30	Based on Domestic surveillance data set extract Nov 2nd 2020 Estimates on symptomatic cases only We have introduced a fudging parameter to fit with hospitalized cases data – mean value=1.5
tau	Proportion of infected who keeps being asymptomatic after the presymptomatic infectious period	General value : 20% Age-stratified [0,10) 0.30 [10,20) 0.22 [20,40) 0.12 [40,60) 0.11 [60,75) 0.13 75+ 0.15	Buitrago-Garcia, D., 2020 Byambasuren, O., 2020 Age-stratified estimates based on Domestic surveillance data set – data extraction Nov 2nd, 2020 The age stratified estimates are on detected case (so probably under-estimation) and are extracted from Domestic surveillance database
$t_{\_pres}$	period of time between onset of infectiousness and onset of symptoms in those developing symptoms OR first infectious period for asymptomatic	2 days	Chen, 2020
t_{sm_early}	period of time between onset of symptoms for mild cases or asymptomatic and detection	Age-stratified Study scenario: 2-4-6 days	Mainly driven by delay between been tested and having the test result
t_{ss_early}	period of time between onset of symptoms for severe cases or asymptomatic and detection	Age-stratified Study scenario: 1 day	Mainly driven by symptoms severity
t_{sm_late}	Period of time between the possibility of being detected and end of infectious period for asymptomatic and mild cases	Will vary according to the length of tsm_early Tsm_early+tsm_late = tsm = 9 days Age-stratified	We assume that duration of infectious period is the same for asymptomatic and mild symptomatic period

t_{sm}	Period of time between onset of symptoms and end of infectious period	Tsm_early+tsm_late = tsm = 9 days Age-stratified	Should be different between asymptomatic and symptomatic according to Kissler , 2020, Singanayagam, 2020, Bullard 2020 Last 6.7 days (asympto) to 10.5 days (symptomatic) on average No age-stratified estimates so far
t_late_q_sm	Period of time between the possibility of been detected and end of quarantine for mild cases	6 days	We still consider a 2 weeks period for total duration of quarantine (latent period + tpres + tsm_early + t_late_q_sm = duration of quarantine)
t_late_q_as	Period of time between end of theoretical presymptomatic infectious period and end of quarantine for asymptomatic	8 days	We still consider a 2 weeks period for total duration of quarantine (latent period + tpres + t_late_q_am = duration of quarantine)
p_{ICU}	proportion of hospitalized cases who require/access to ICU in Hospital	Not used	
$t_{sorting}$	period of time for sorting severe cases in hospital (before general service orICU)	1 day	We assume it takes one day on average between when a severe case arrives in the hospital and when the case is sorted to the appropriate service.
m_g_early	mortality rate for severe cases in hospital	[0,10) 0 [10,20) 0.0076 [20,40) 0.015 [40,60) 0.055 [60,75) 0.18 75+ 0.36	Based on StatCan Hospitalization DashBoard – data extraction Nov 2nd, 2020 – note: mortality are for all hospitalized (ICU and non ICU)
m_ICU_early	mortality rate for severe cases dying in hospital (ICU)	Not used --	--
t_hr_early	period of time between first day in hospital after sorting, and death, for dead cases.	[0,10) 3 [10,20) 3 [20,40) 7 [40,60) 8 [60,75) 9 75+ 10 Age-stratified	based on 'Hospitalisation and length of stay (LOS) of COVID-19 cases' version Oct 16th 2020 Whitaker (US), Rizzo (US), Gold (US)
th_late	period of time between second period of hospitalization, and recovery, for recovered cases.	1 day (the minimum without having to delete the compartment) Age-stratified	There are no evidence that the length of stay for survivor is longer than the length of stay for non-survivor.

m_g_denied	mortality rate for severe cases dying at home because they are not able to access hospital care	Not used	Not calibrated because this parameter has no impact on the results (e.g. attack rate) presented in this article'
m_{ICU-}	mortality rate for severe cases dying in hospital because they are not able to access ICU	Not used	
ICU capacity		Find estimate on national capacity	
w	Percent of recovered who loose their immunity	Age-stratified – by default value= 0%	
t_im	Duration of immunity for recovered	Age-stratified – by default value: 200 days	Set at zero for simulations presented here

The model was implemented in R using RStudio, using the following packages: EpiSim, adaptivetau, deSolve, dplyr, DT, forcats, ggplot2, htmlwidgets, lhs, magrittr, openxlsx, plotly, readxl, scales, tidyr, and triangle.

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