A Stochastic Model of COVID-19 Infections During a Large-Scale Canadian Army Exercise

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Canada

Overview

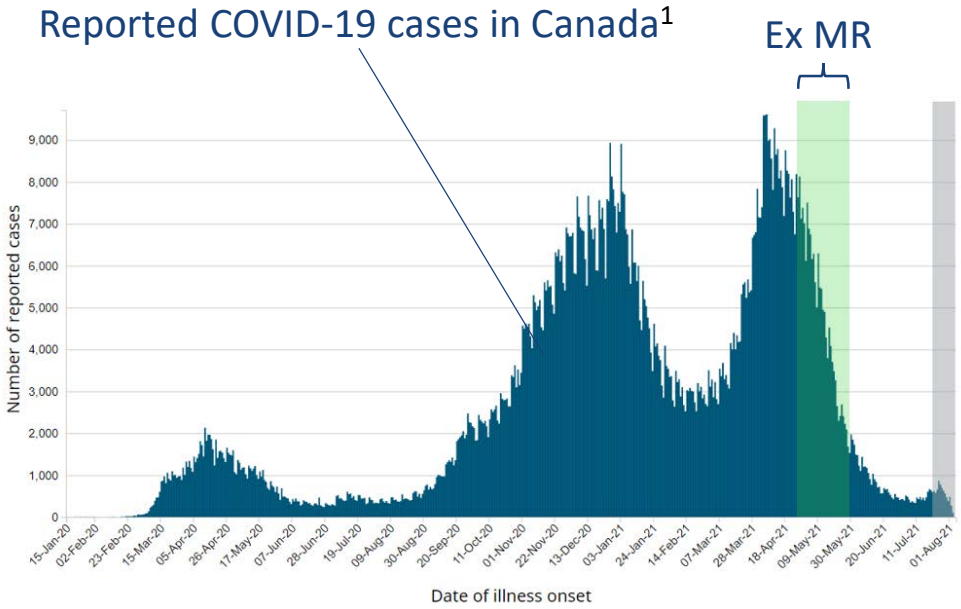
Exercise MAPLE RESOLVE (Ex MR)

- Canadian Army's largest and most complex annual training exercise for high readiness
- Thousands of participants: predominantly Canadian Armed Forces (CAF) and some international participants
- Takes place in spring at Canadian Forces Base (CFB) Wainwright, Alberta, Canada
- Cancelled in 2020 due to COVID-19 pandemic
- In 2021, Canadian Army command proceeded with planning Ex MR incorporating a comprehensive COVID-19 risk mitigation strategy

Overview

COVID-19

- Risk mitigation at the exercise included:
  - Limit total participation to 2500
  - Reduce number of international participants
  - Isolated work zones and cohorts
  - Physical distancing, masks, sanitizing
  - First dose of vaccine offered at exercise
- Timing of Ex MR 2021 coincided with a third wave of COVID-19 in Canada driven by the Alpha variant (B.1.1.7)
- Potential spread of COVID-19 uncertain
  - Difficult to plan, lacked evidence to support decision to proceed or not



[1]"COVID-19 daily epidemiology update," Government of Canada

Overview

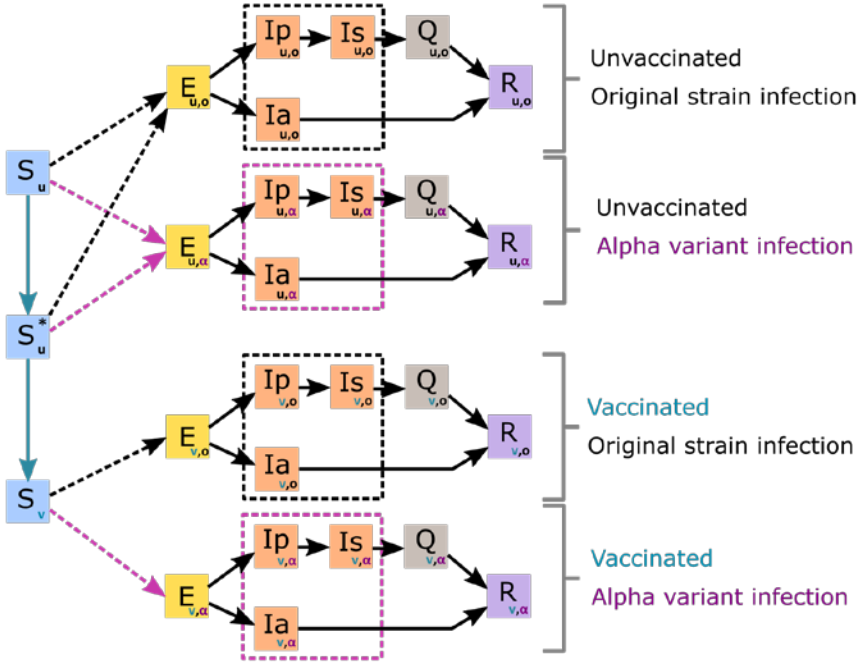
Approach

- Developed an SEIR (susceptible, exposed, infected, recovered) model of the Ex MR setting to simulate the spread of COVID-19 during the exercise
- Key questions:
  - What is the potential scale of COVID-19 infections during exercise?
  - What will be the impact of increasing prevalence of Alpha variant?
  - What will be the impact of offering first dose of vaccine mid-exercise?
  - What is the potential for departing participants to bring infections home to their communities?

Ex MR details

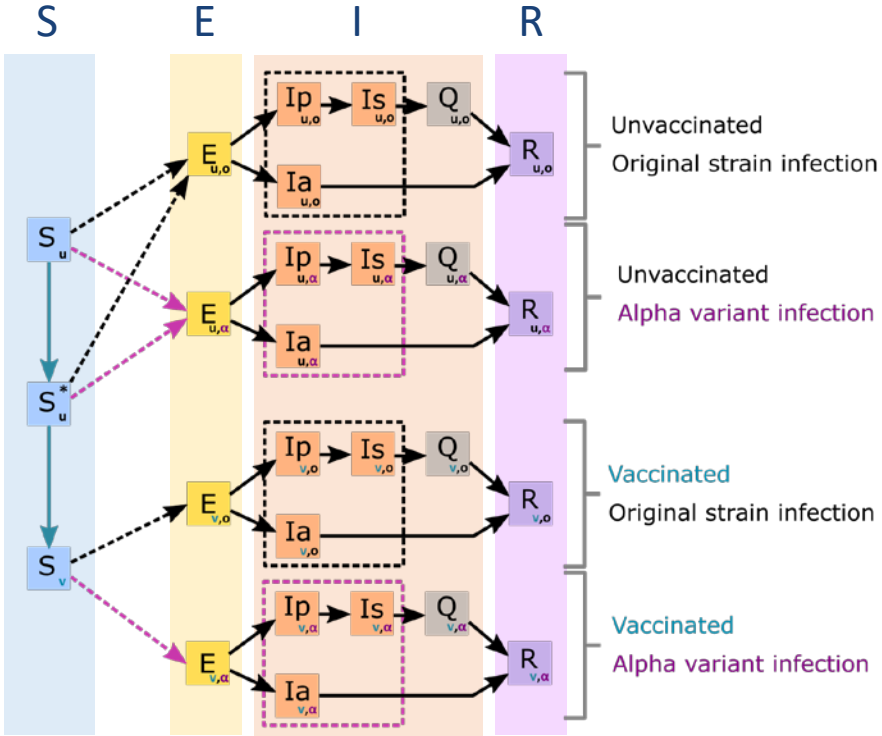
- 2500 total participants, predominantly CAF members from Edmonton, Alberta area
- Varied arrival and departure times between early April and early June
- Participants required to self-isolate at home for seven days and obtain a negative COVID-19 test immediately prior to arrival
- Ex MR activities divided into isolated zones
    1. Primary training zone (PTZ)
    2. Support and base zone (SBZ)
- Personnel within zones separated into cohorts of size 40
- On-site medical staff present to quarantine and treat COVID-19 cases and conduct vaccination clinic over 4 days (April 27 – 30) providing first dose of Moderna vaccine

SEIR model of Ex MR 2021

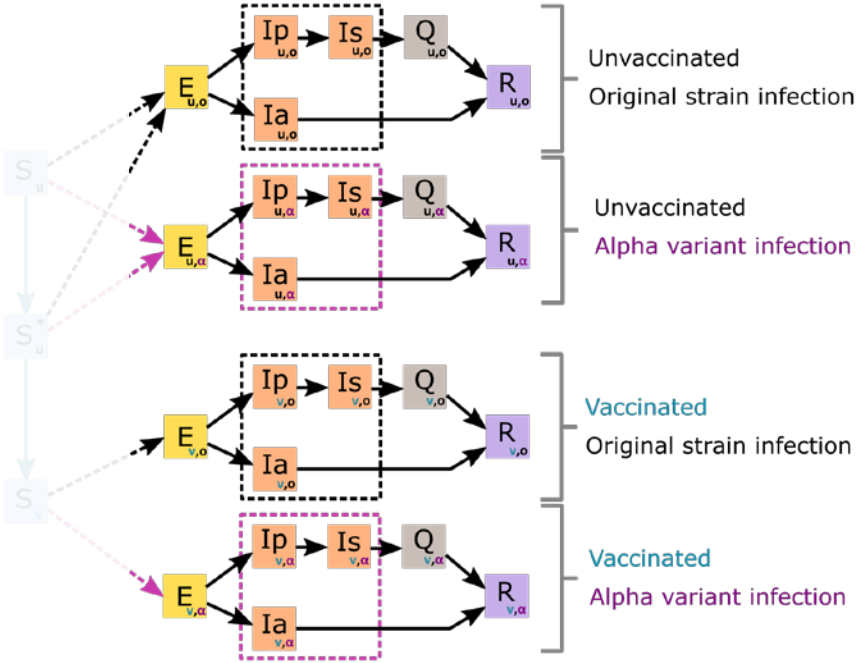


SEIR model of Ex MR 2021

- Basic SEIR structure is present, but with additional compartments and flows to model the Ex MR scenario



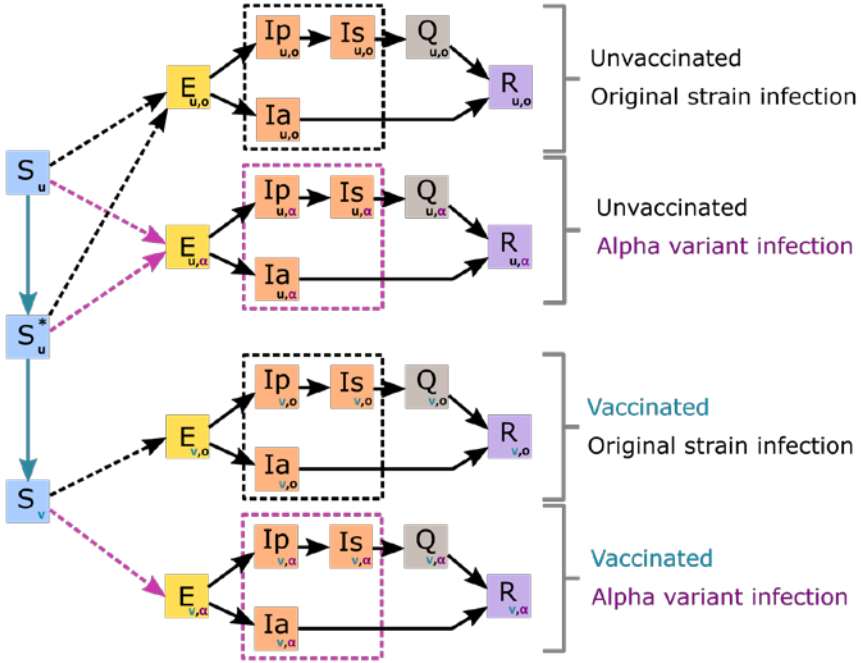
SEIR model of Ex MR 2021



- Four infection paths depending on vaccination status and COVID-19 variant
- Alpha variant (α) has increased transmission compared to original strain (o)
- Vaccinated population (v) has decreased transmission compared to unvaccinated population (u)

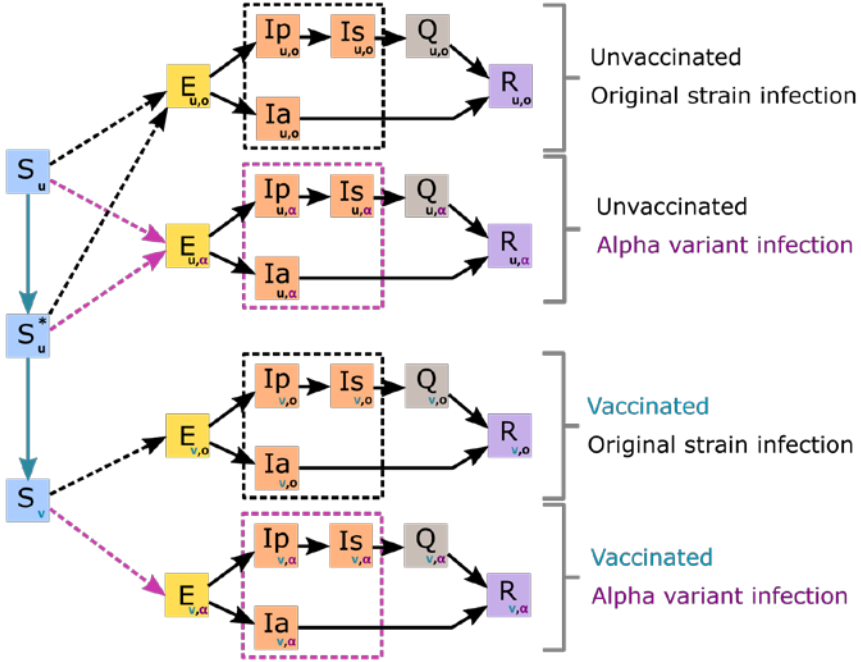
SEIR model of Ex MR 2021

- New exposures to the Alpha variant (- - - →) are caused by individuals infected with the Alpha variant outside quarantine ([ ])
- New exposures to the original strain (- - - →) are caused by individuals infected with the original strain outside quarantine ([ ])



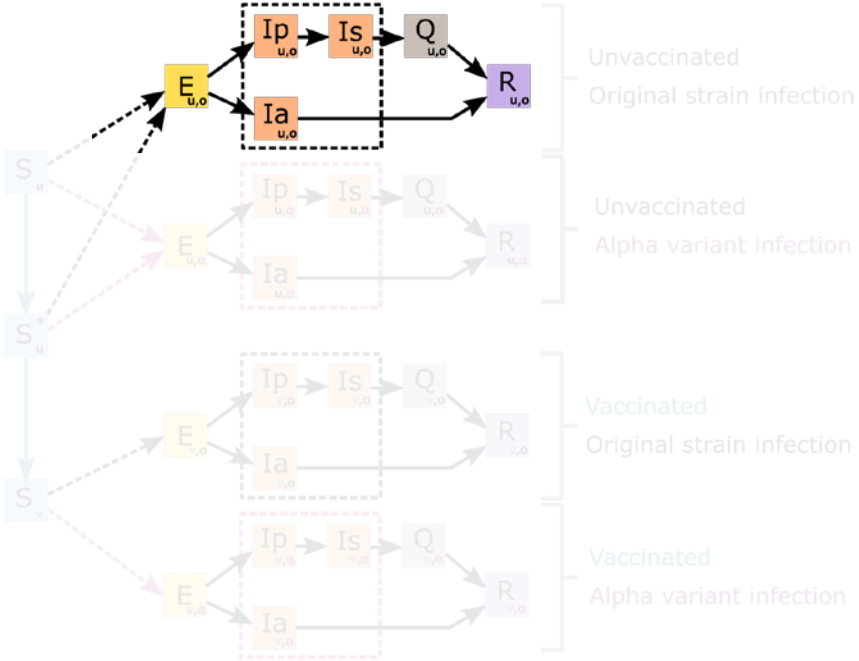
SEIR model of Ex MR 2021

- The probability of being exposed is given by $B \cdot I/N$
- B is the transmission rate which depends on vaccination status and the variant
- B also varies randomly from day to day according to a beta distribution (some days will see higher transmission than others)
- I/N is the proportion of the population infected with the specific strain



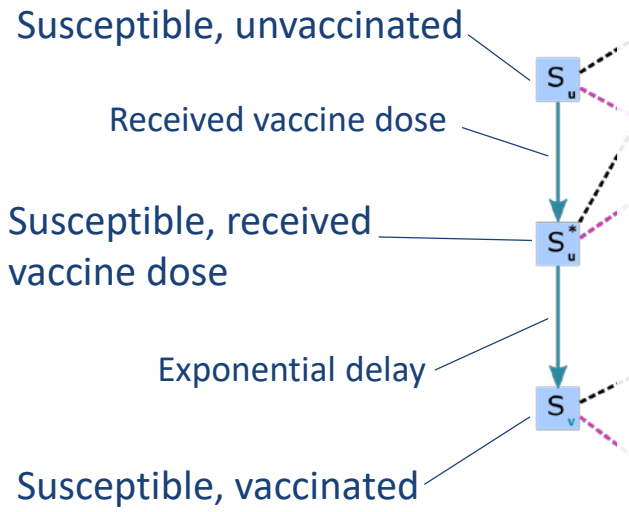
SEIR model of Ex MR 2021

- Exposed individuals (*E*) eventually become either asymptomatic (*Ia*) or pre-symptomatic (*Ip*)
- Pre-symptomatic infections eventually become symptomatic (*Is*), at which point they will present as a detected COVID-19 case and will be shortly quarantined (*Q*) until they recover (*R*)
- Asymptomatic infections remain in the population until they recover

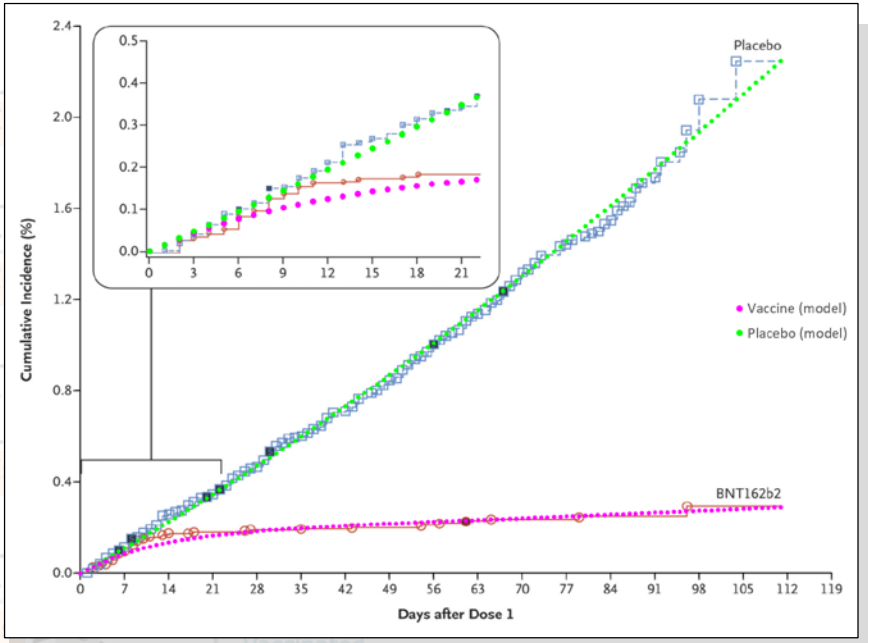


SEIR model of Ex MR 2021

- Multiple susceptible compartments model vaccination status



Vaccine model fit to Pfizer trial data[2]



[2]F. P. Polack et al., "Safety and Efficacy of the BNT162b2 mRNA Covid-19 Vaccine," *N Engl J Med,* vol. 383, pp. 2603-2615, December 2020.

PyCoMod

- The compartment model was implemented in PyCoMod (Python Compartment Modelling) which was developed to support this and similar COVID-19 research for the CAF
- PyCoMod is a Python package that is publicly available on github (https://github.com/DND-DRDC-RDDC/OS_PyCoMod)
- Install it: `pip install git+https://github.com/DND-DRDC-RDDC/OS_PyCoMod.git`
- Key features:
  - Stochastic compartment flows and Monte-Carlo simulations
  - Input and output data management and plotting
  - Vectorized runs
  - Object oriented design and model nesting

Key parameters

Vaccine

- Estimated uptake: 80% (also ran simulation at 0% uptake to observe impact of vaccine)
- Average lag in attaining efficacy: 11 days
- Long-term efficacy against symptomatic infection: 95%
- Reduction in probability of onward transmission: 60%

COVID-19 prevalence

- Point prevalence among general population in Edmonton, Alberta approaching start of Ex MR: 2.5%
- Alpha variant was estimated to make up approximately 50% of current infections and growing, therefore we ran three scenarios: 50%, 75% and 100%
- DRDC's missed infection calculator[3] was used to estimate the probability of an asymptomatic infection entering undetected after pre-quarantine and testing: 0.35%

[3]https://decision-support-tools.com/calculator

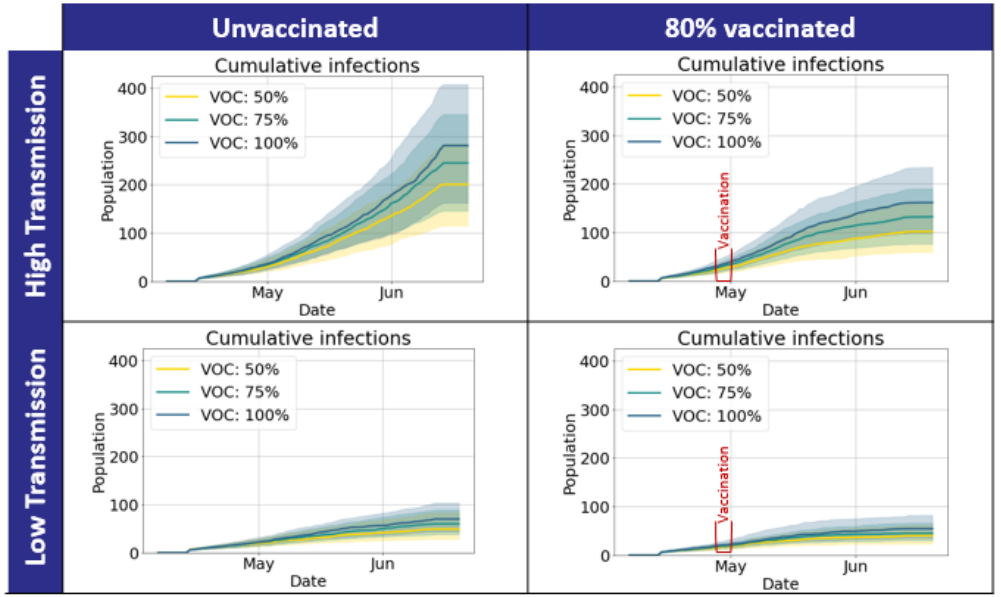
Key parameters

Transmission rates

- For the primary training zone, we estimated transmission rates based on two published COVID-19 studies in military training settings known at the time (no CAF data was available):
  - PTZ high-transmission rate: 0.19 (based on US Marine recruit study)
  - PTZ low-transmission rate: 0.11 (based on US Air Force recruit study)
- For the support and base zone, we assumed transmission to be similar to the general CAF working environment, therefore the estimate is based on COVID-19 case data for the general Canadian population and the relative per capita number of infections in the CAF
  - SBZ transmission rate: 0.1
- For both zones, the Alpha variant is 50% more transmissible than the nominal transmission rates, above

Results: Cumulative infections

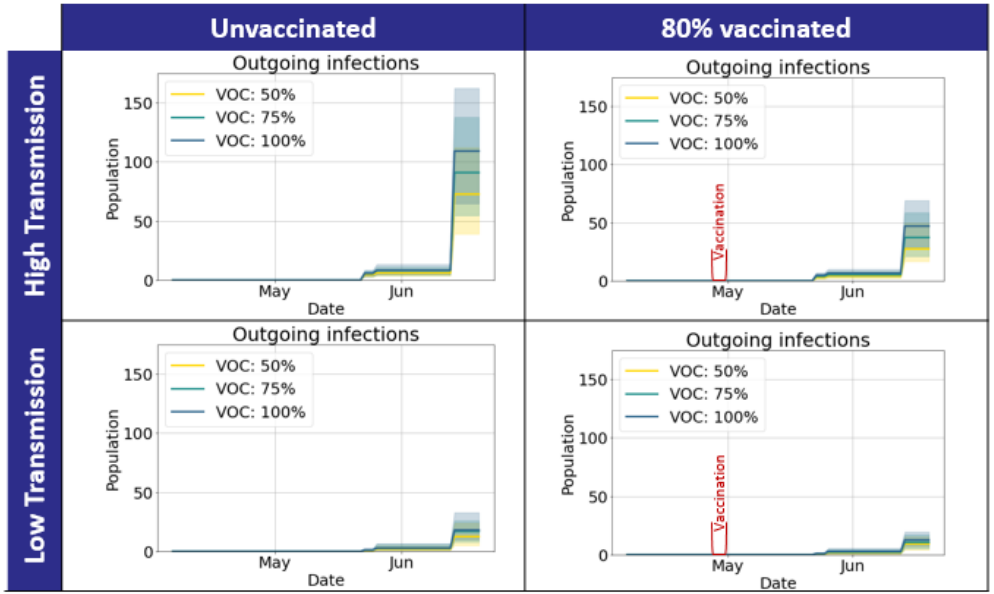
- Cumulative infections include symptomatic and asymptomatic infections
- **Best case** (low transmission, 80% vaccinated, 50% Alpha): <50 infections
- **Worst case** (high transmission, no vaccination, 100% Alpha): >250 infections
- **"Realistic" range** (50% Alpha, 80% vaccination): 40 – 100 infections
- Vaccination has a significant impact, especially in the high transmission scenario, reducing the number of infections by about 50%
- Increased prevalence of Alpha variant causes 40% to 50% more infections



Point Prevalence (PP)	VOC Prevalence	Range of median # of cumulative infections		
		No vaccination	Vaccination	Difference
2.5%	50%	49 – 203	40 – 102	9 – 101
	75%	60 – 253	45 – 134	15 – 119
	100%	70 – 282	54– 162	16 – 120

Results: Outgoing infections

- Outgoing infections include undetected infections (exposed, pre-symptomatic and asymptomatic) that leave the exercise
- **Best case** (low transmission, 80% vaccinated, 50% Alpha): <10 infections
- **Worst case** (high transmission, no vaccination, 100% Alpha): >100 infections
- **"Realistic" range** (50% Alpha, 80% vaccination): 10 - 30 infections
- Again, vaccination has a significant impact, especially in the high transmission scenario reducing the number of outgoing infections by about 60%
- Increased prevalence of Alpha variant causes 40% to 60% more outgoing infections



Point Prevalence (PP)	VOC Prevalence	Range of median # of outgoing infections		
		No vaccination	Vaccination	Difference
2.5%	50%	13 – 73	9 – 28	4 – 45
	75%	17 – 91	11 – 37	6 – 54
	100%	18 – 110	13 – 47	5 – 63

Conclusions

- Operating in a COVID-19 environment is the new reality for the CAF and other militaries
- We present an SEIR-derived model that was used to estimate the scale of COVID-19 transmission at the Canadian Army's largest military exercise, Ex MR
- The results show the impact of various important factors including the presence of multiple variants of the virus, vaccination while at the exercise, and a range of transmission rates
- A particular concern was the risk that departing exercise participants might spread infections to their home communities after the exercise, however our results show that the probable number of such events is small
- This work provided the Canadian Army with COVID-19 risk information necessary to make decisions about conducting the exercise and whether to proceed with the exercise during the ongoing pandemic situation

Questions?