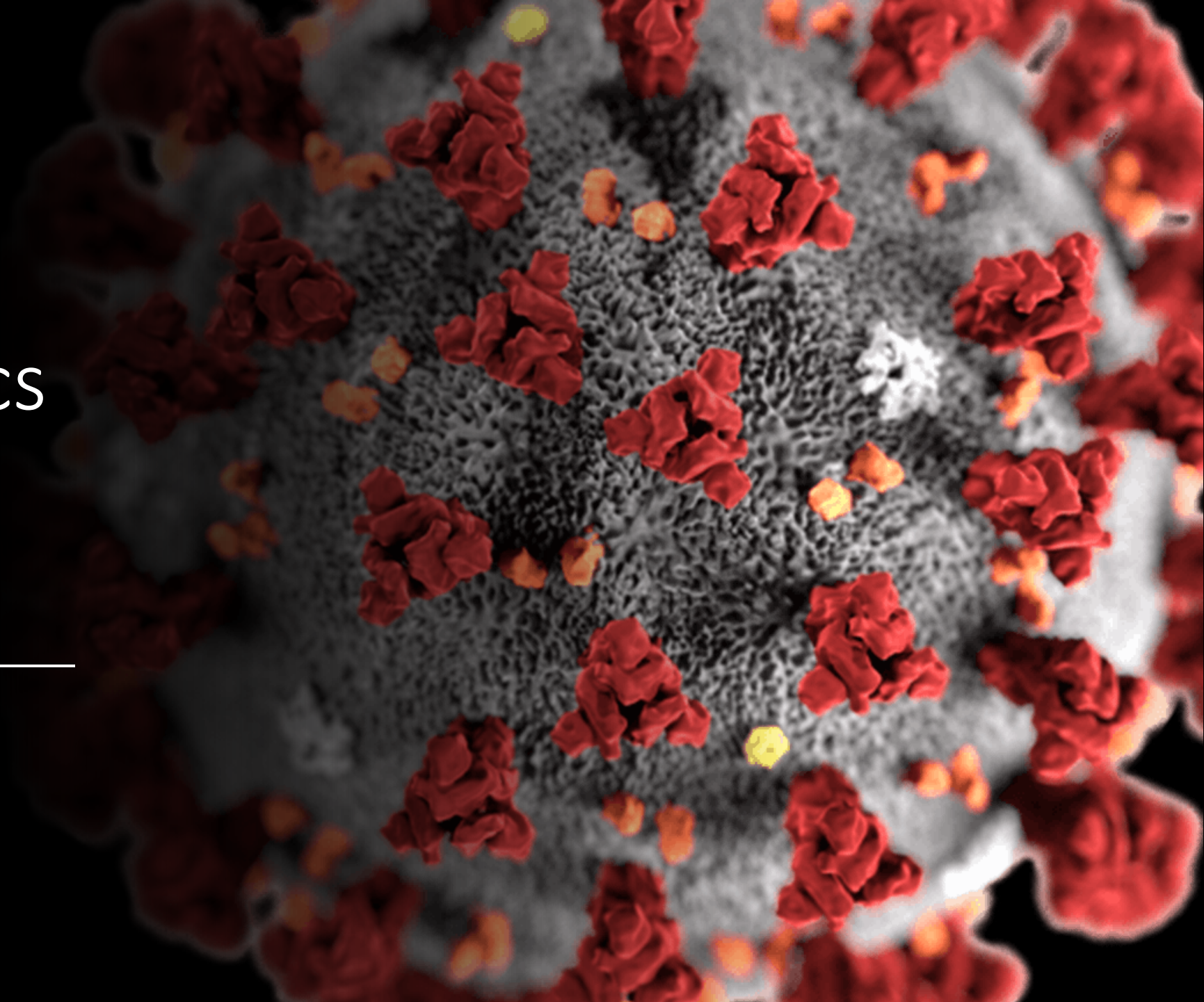
Applying Particle Physics to COVID-19 Modelling



Dean Karlen
University of Victoria and TRIUMF

IPP 50th Anniversary Symposium

May 28-29, 2022, Ottawa

April 2020

- Began working with BC COVID-19 modelling group (academics)
- April 16 – T2K results highlighted on the cover of Nature
- April 18 – Engaged with Nature to retract their story on COVID-19 antibody study by Stanford group. (Mistake in statistical treatment!)

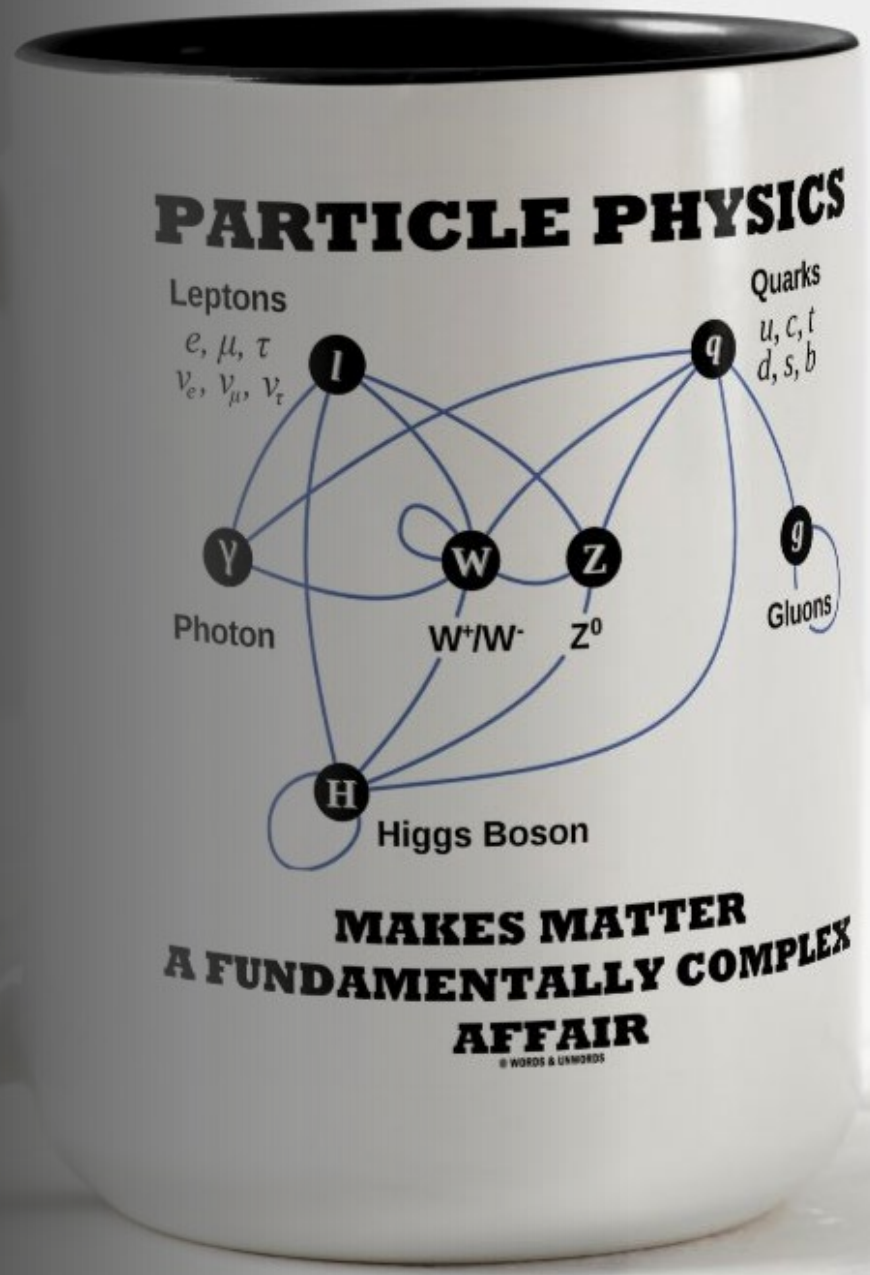
NEWS · 17 APRIL 2020

UPDATE 19 APRIL 2020

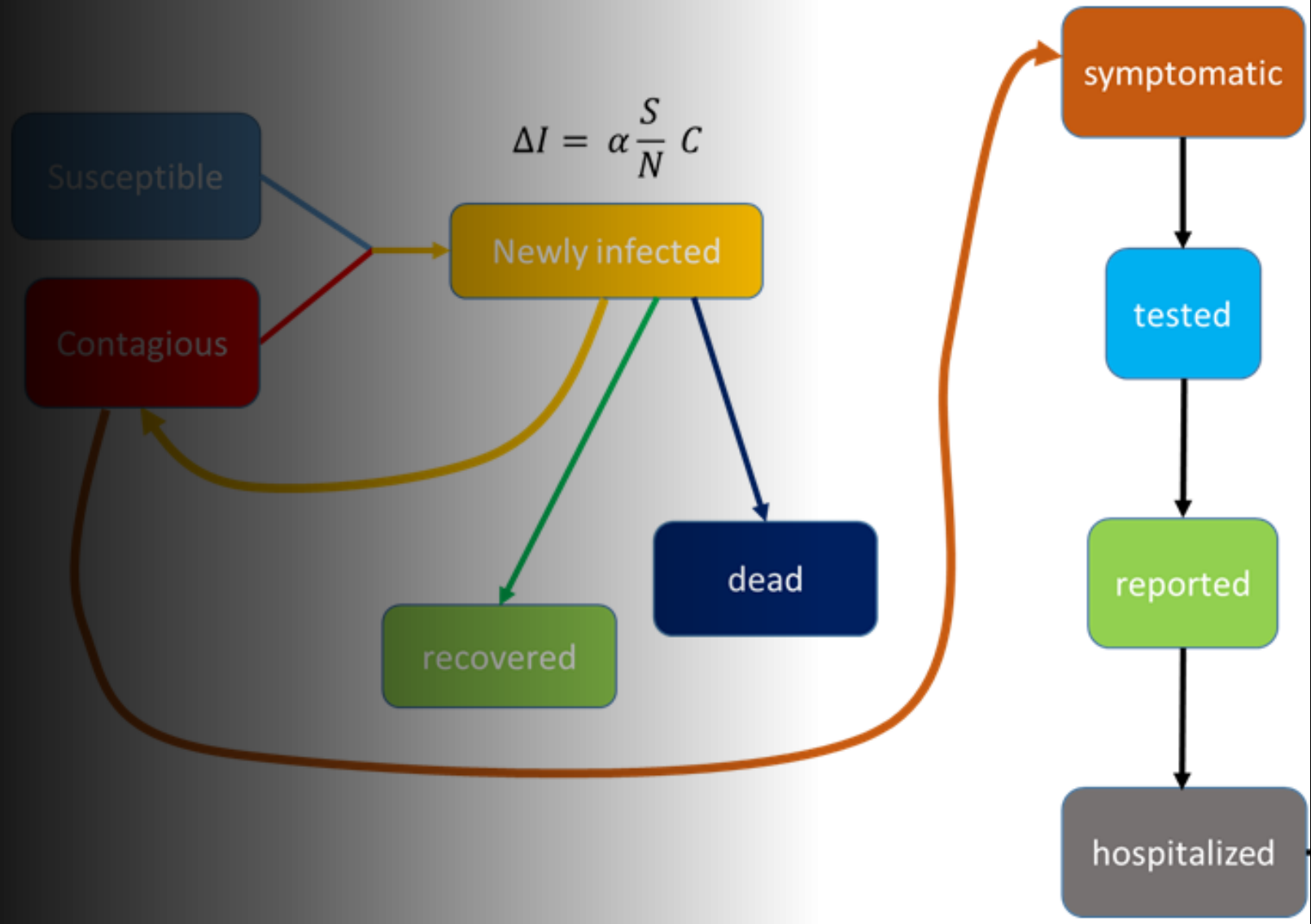
Antibody tests suggest that coronavirus infections vastly exceed official counts

Study estimates a more than 50-fold increase in coronavirus infections compared to official cases, but experts have raised concerns about the reliability of antibody kits.

The Standard Model

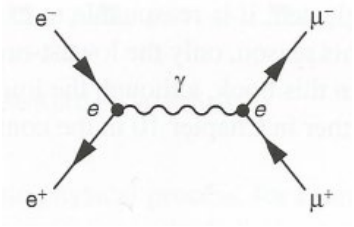


A COVID-19 Model



Dean Karlen / UVic and TRIUMF

A COVID Model



$$\Delta I = \alpha \frac{S}{N} C$$

$S(t=0) = N$

$C(t=0) = C_0$

Susceptible

Contagious

Newly infected

$p = 0.9$
$\mu_t = 3.$
$\sigma_t = 1.$

$p = 0.01$
$\mu_t = 21$
$\sigma_t = 5$

$p = 0.99$
$\mu_t = 14$
$\sigma_t = 5$

dead

recovered

$p = 0.9$
$\mu_t = 3.$
$\sigma_t = 1.$

symptomatic

$p = 0.8$
$\mu_t = 3.$
$\sigma_t = 1.$

tested

$p = 0.95$
$\mu_t = 5.$
$\sigma_t = 2.$

reported

$p = 0.2$
$\mu_t = 3.$
$\sigma_t = 2.$

hospitalized

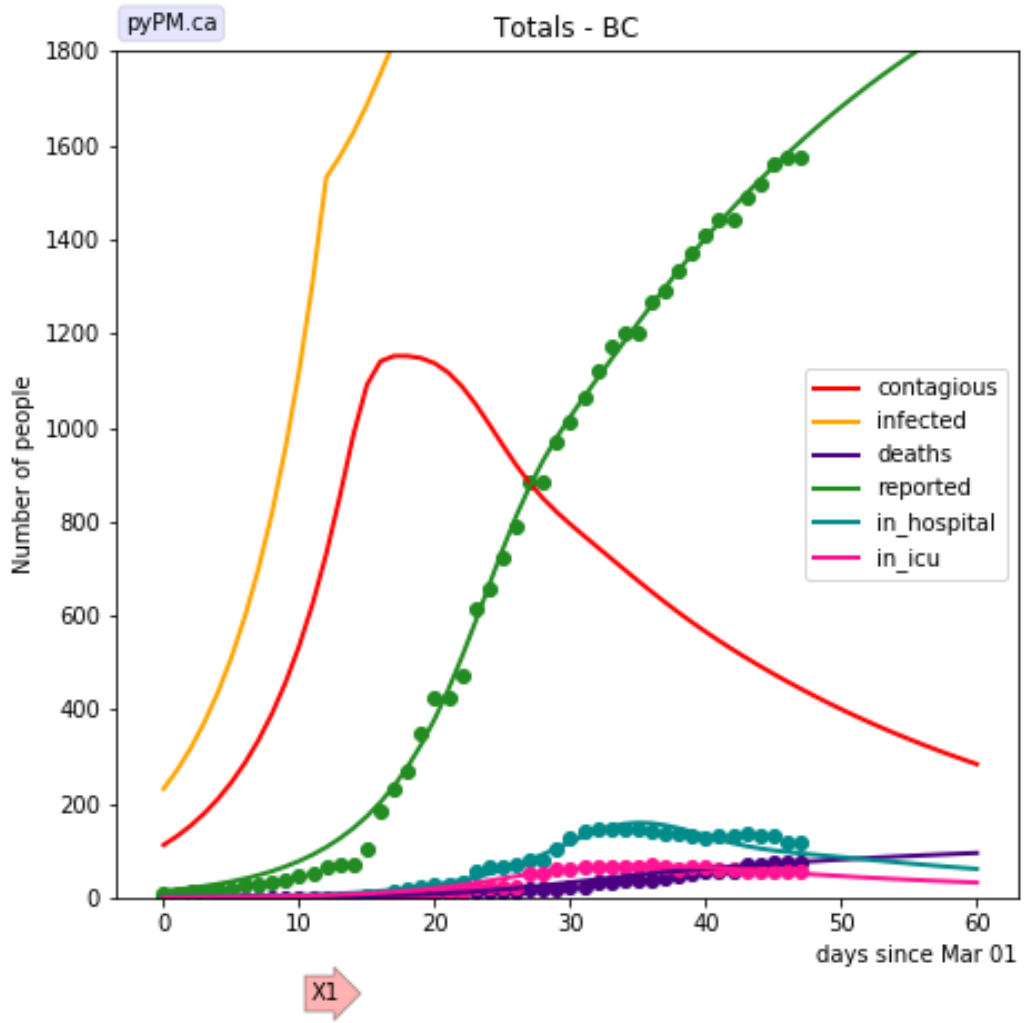
$\mu_t = 14.$
$\sigma_t = 5.$

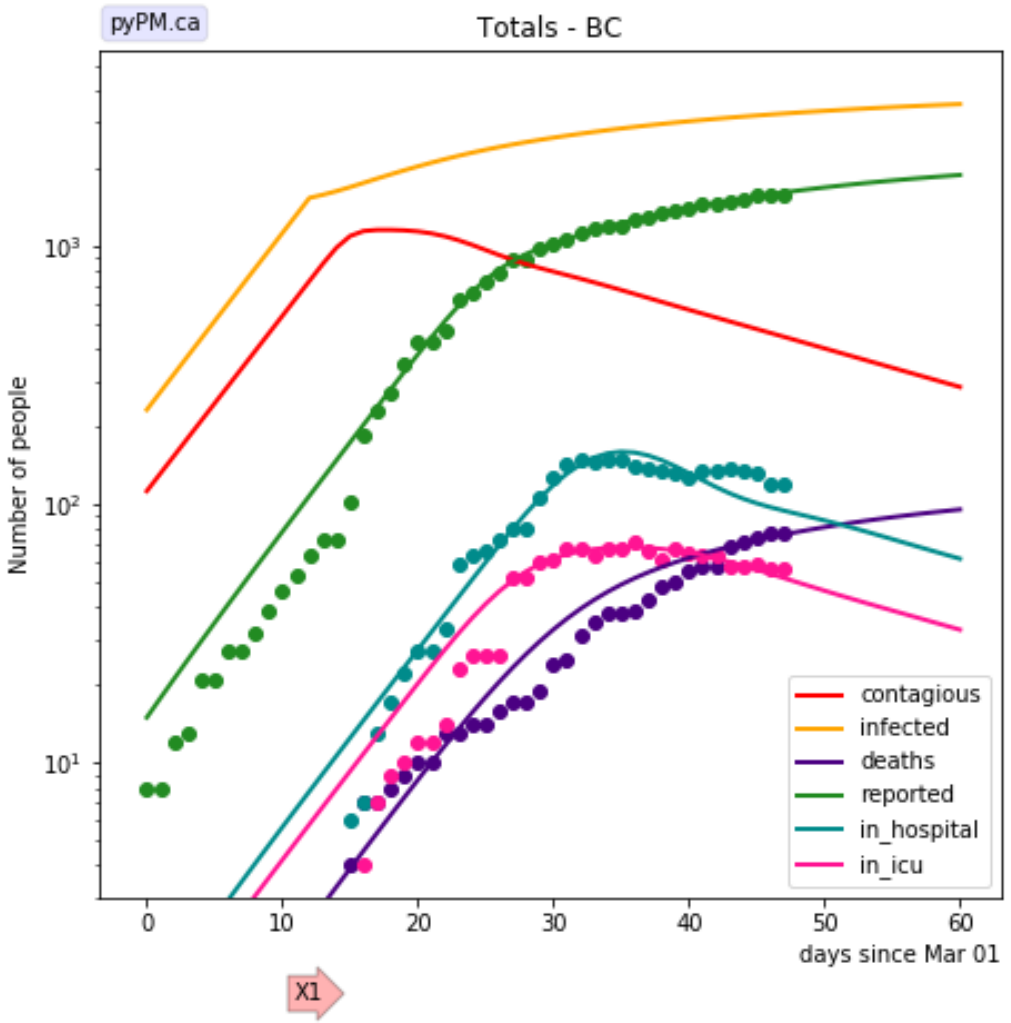
released

The transmission rate α is the mean number of people that a contagious person infects per day in a naïve population

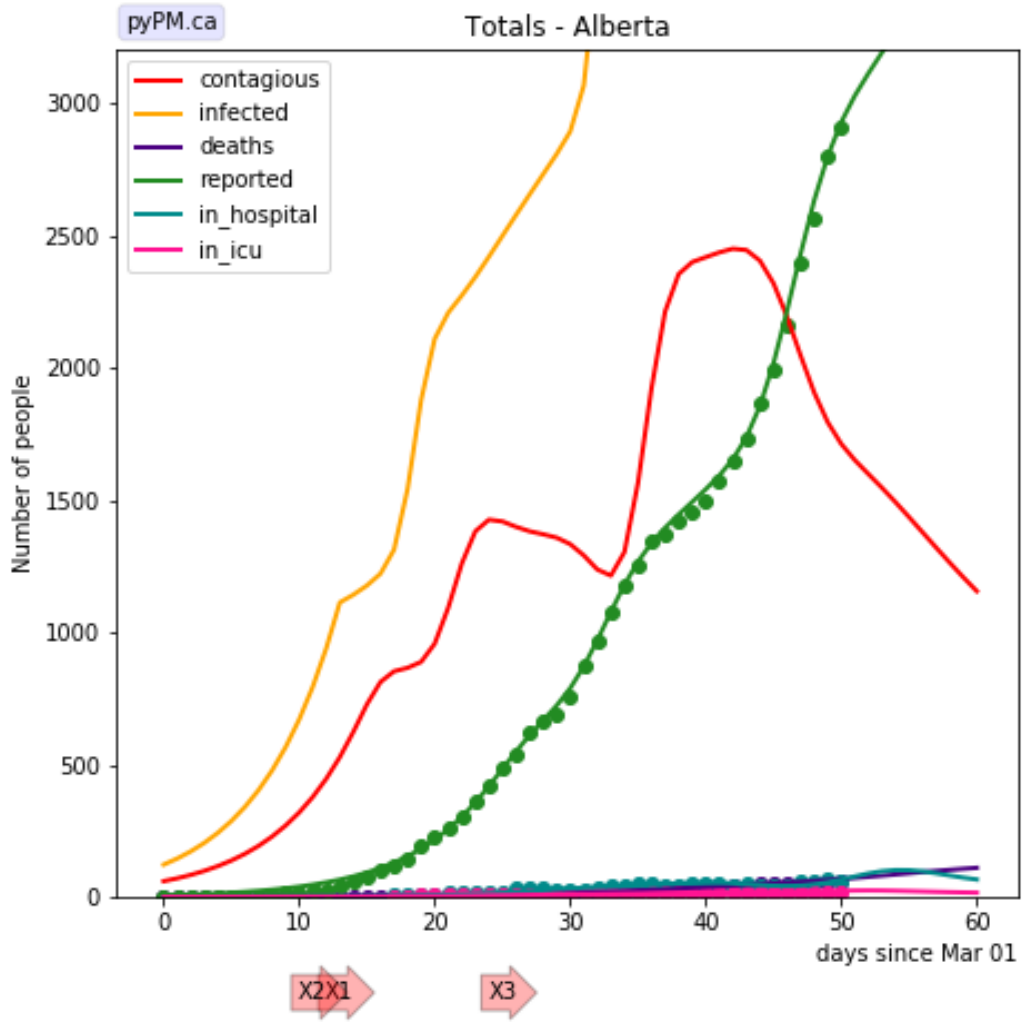
Lines represent population flows (probabilistic and with delays): “propagators”

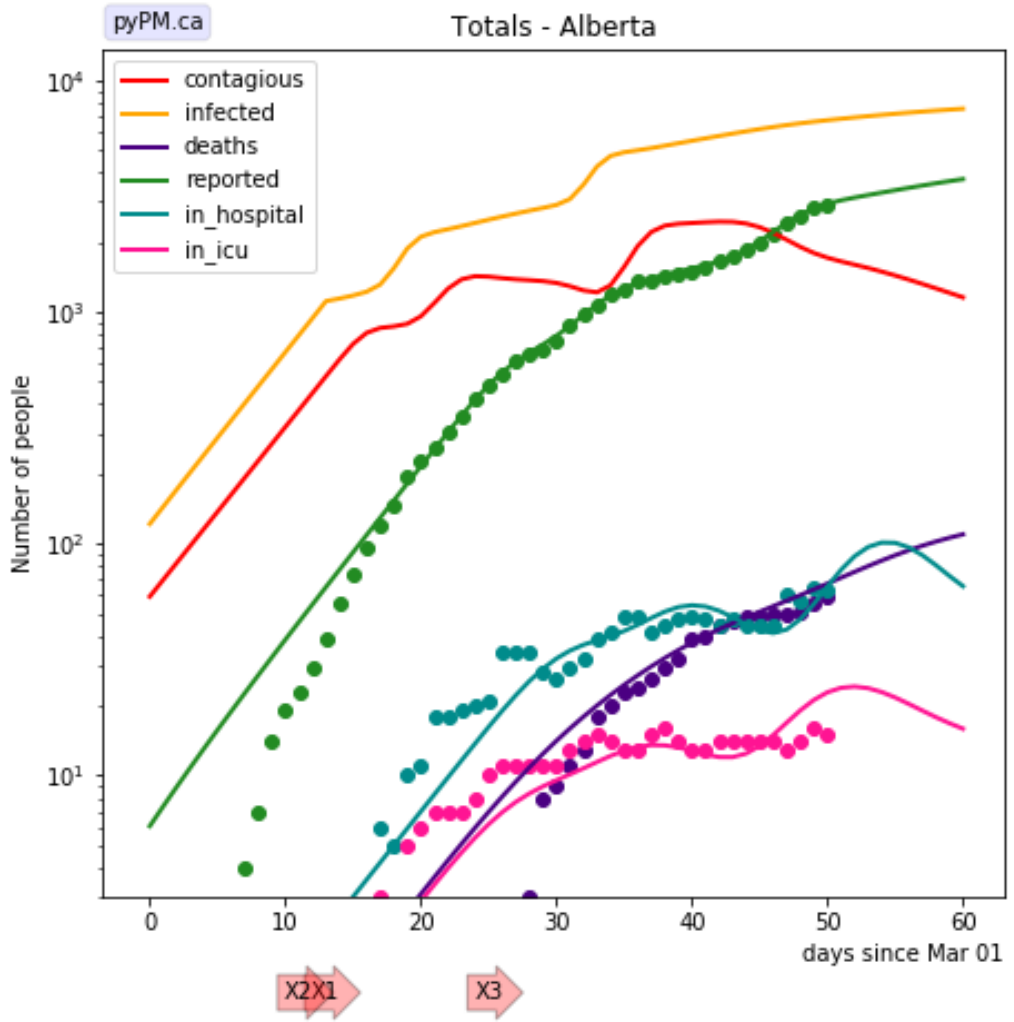
Early BC Data



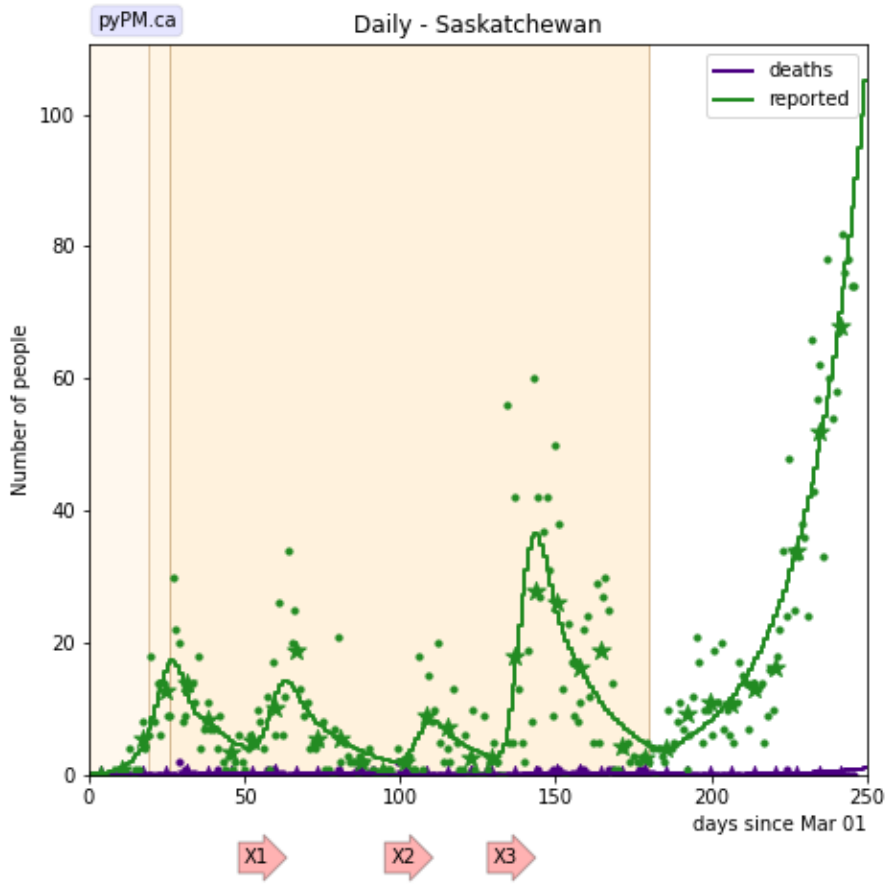


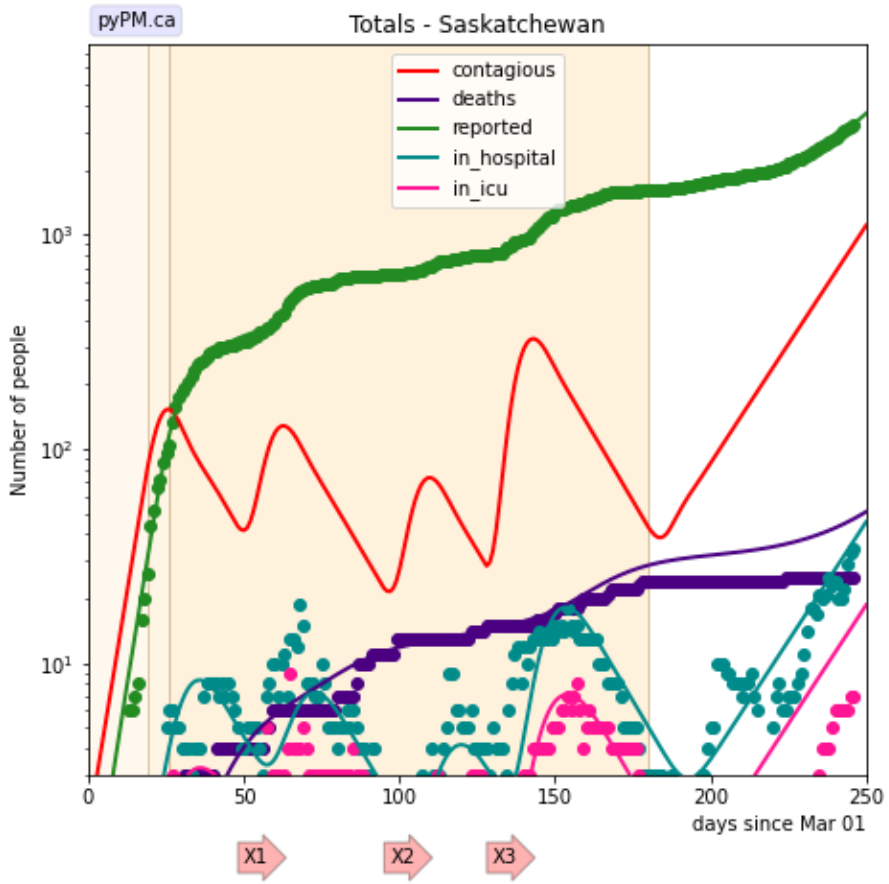
Early Alberta data





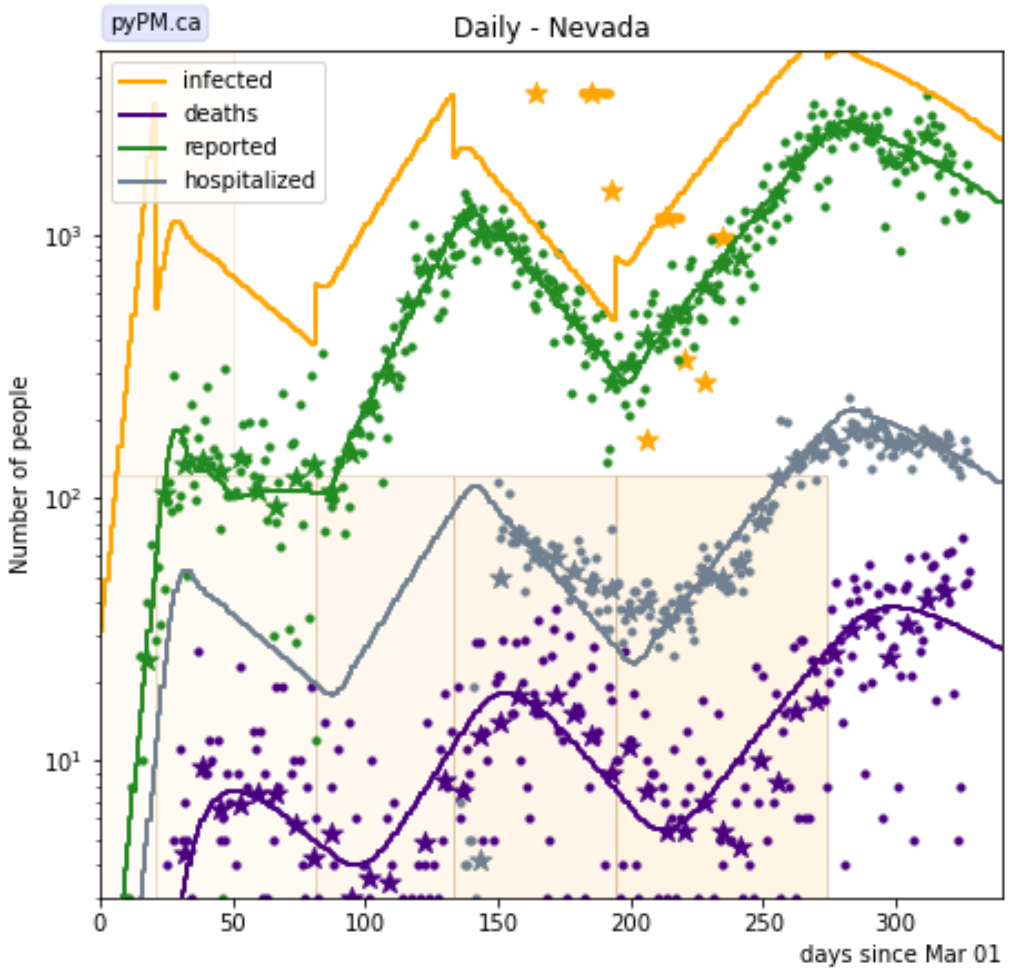
Saskatchewan

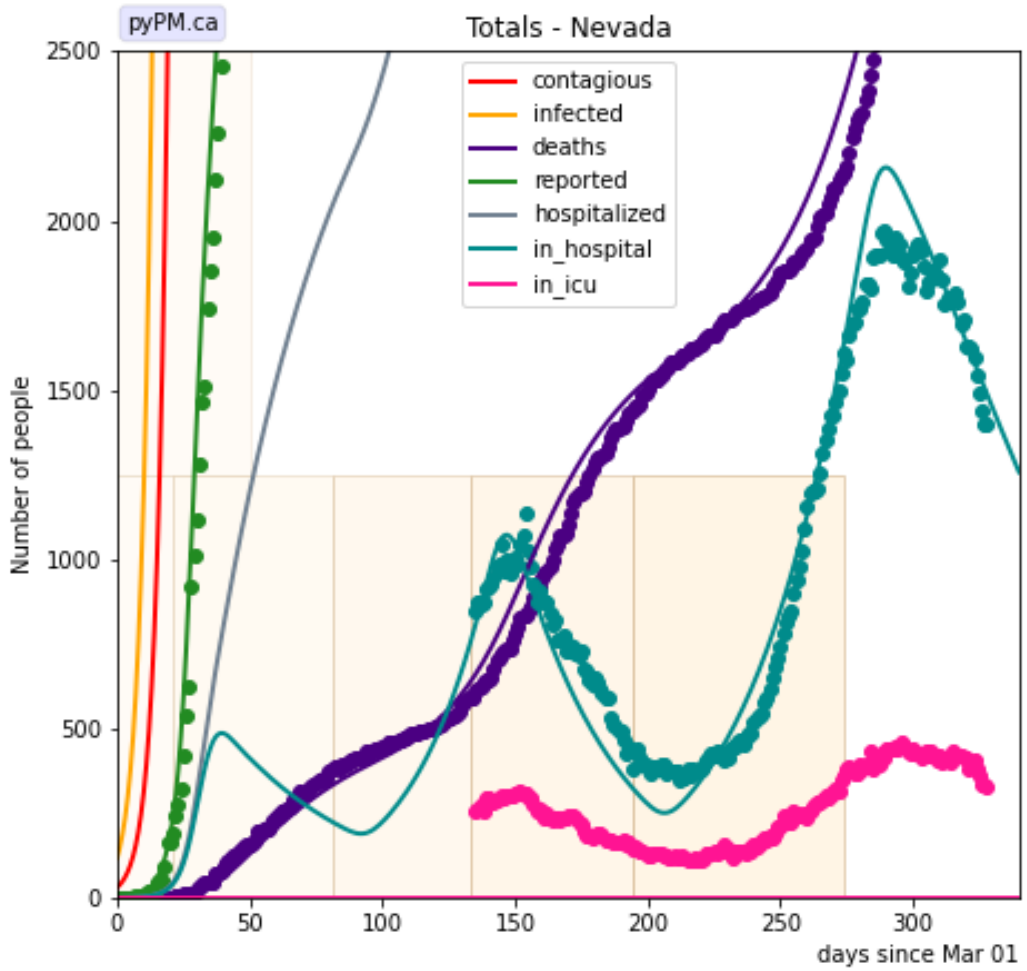




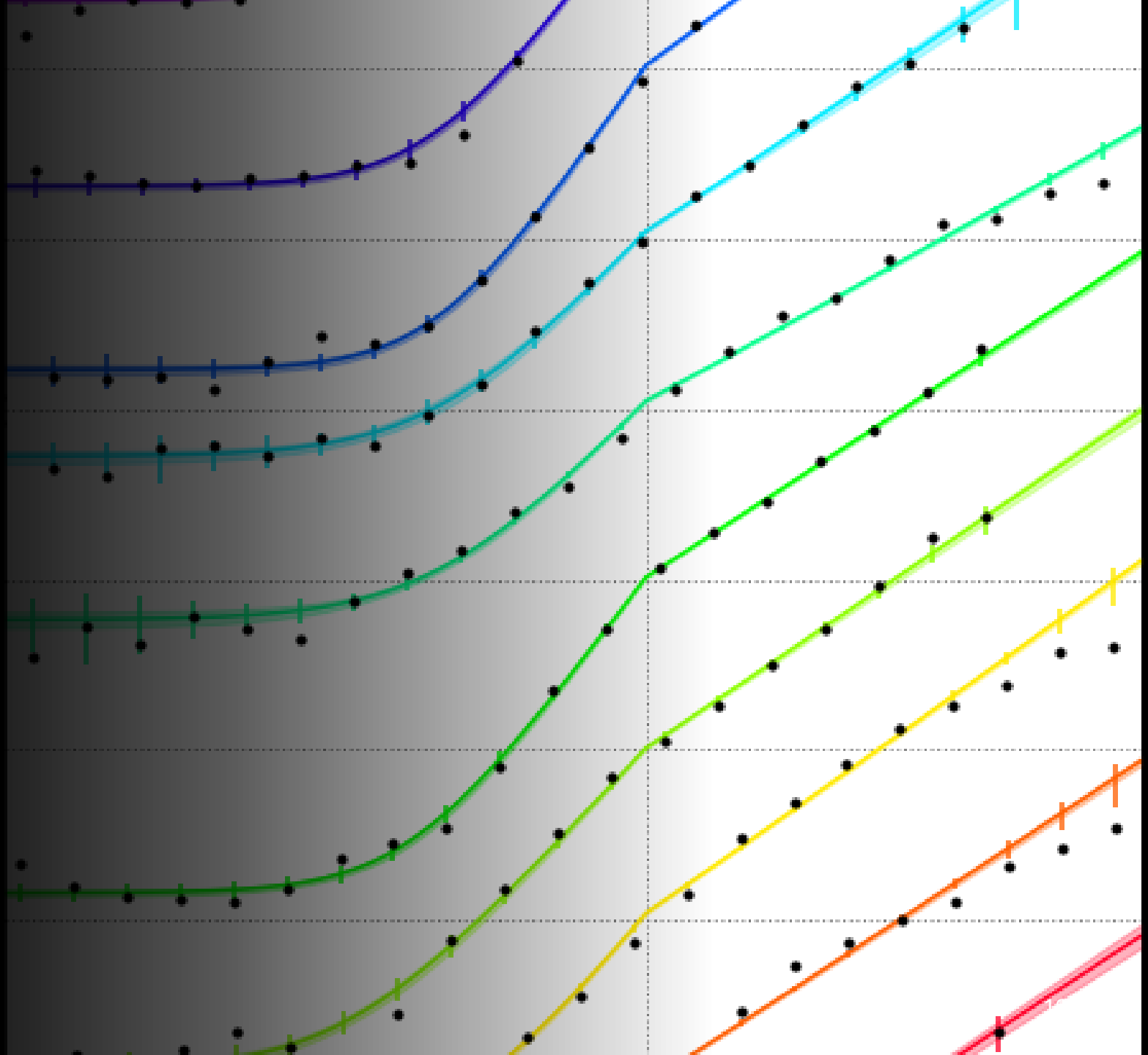
Nevada

Typical growth rates: between -5% per day and +5% per day





The Rise of Alpha (VoC)



2022-05-28

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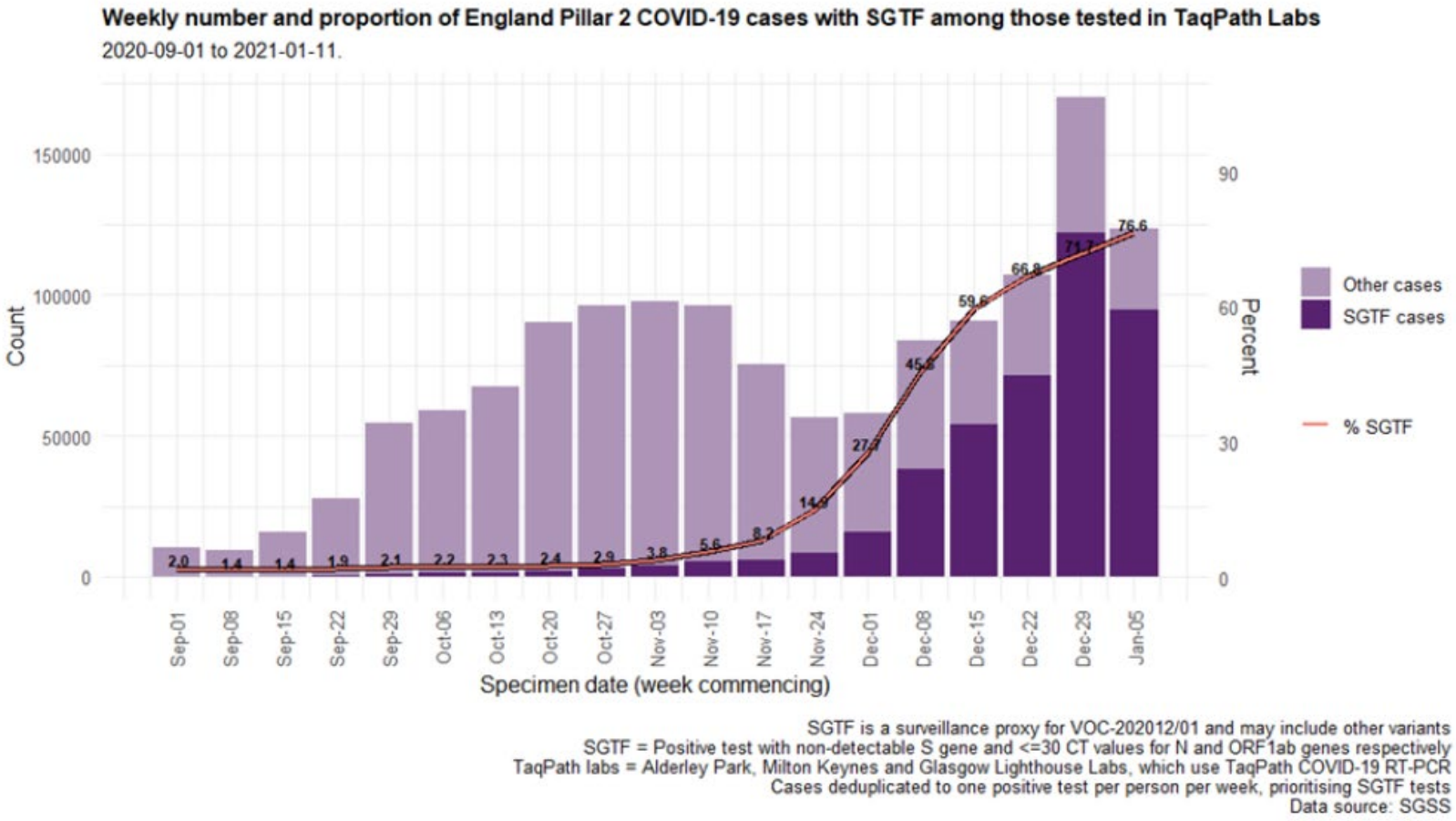
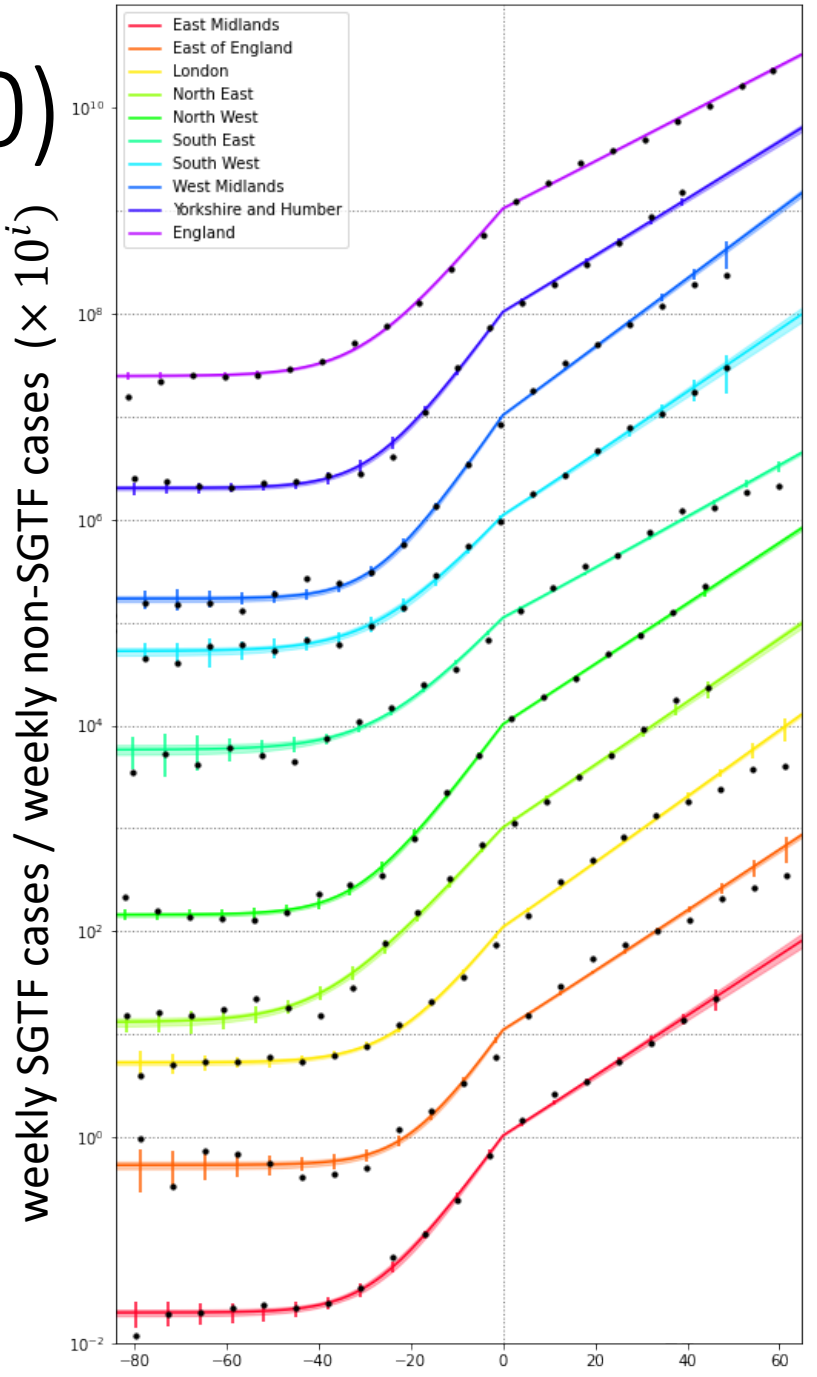
UK rise in SGTF cases (Nov 2020)

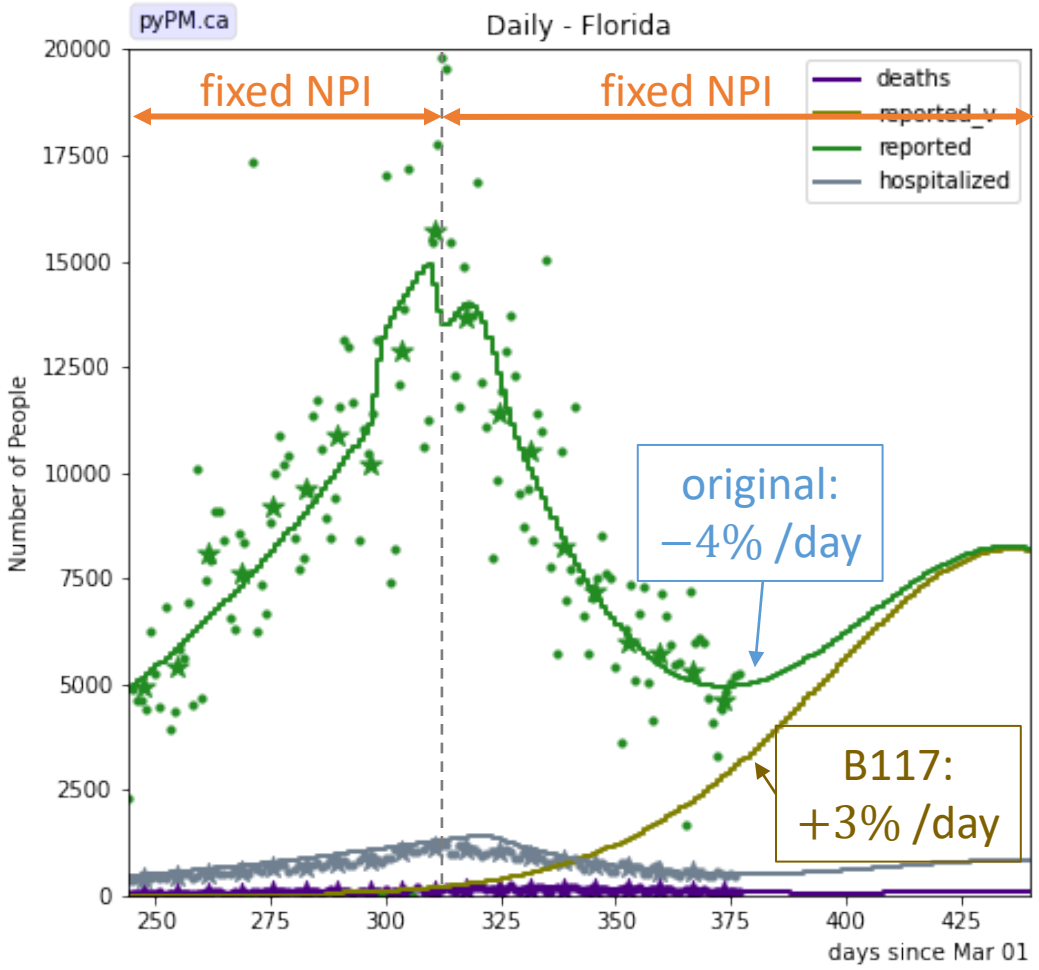




B.1.1.7 growth advantage 14%/day, reduced to 8% per day

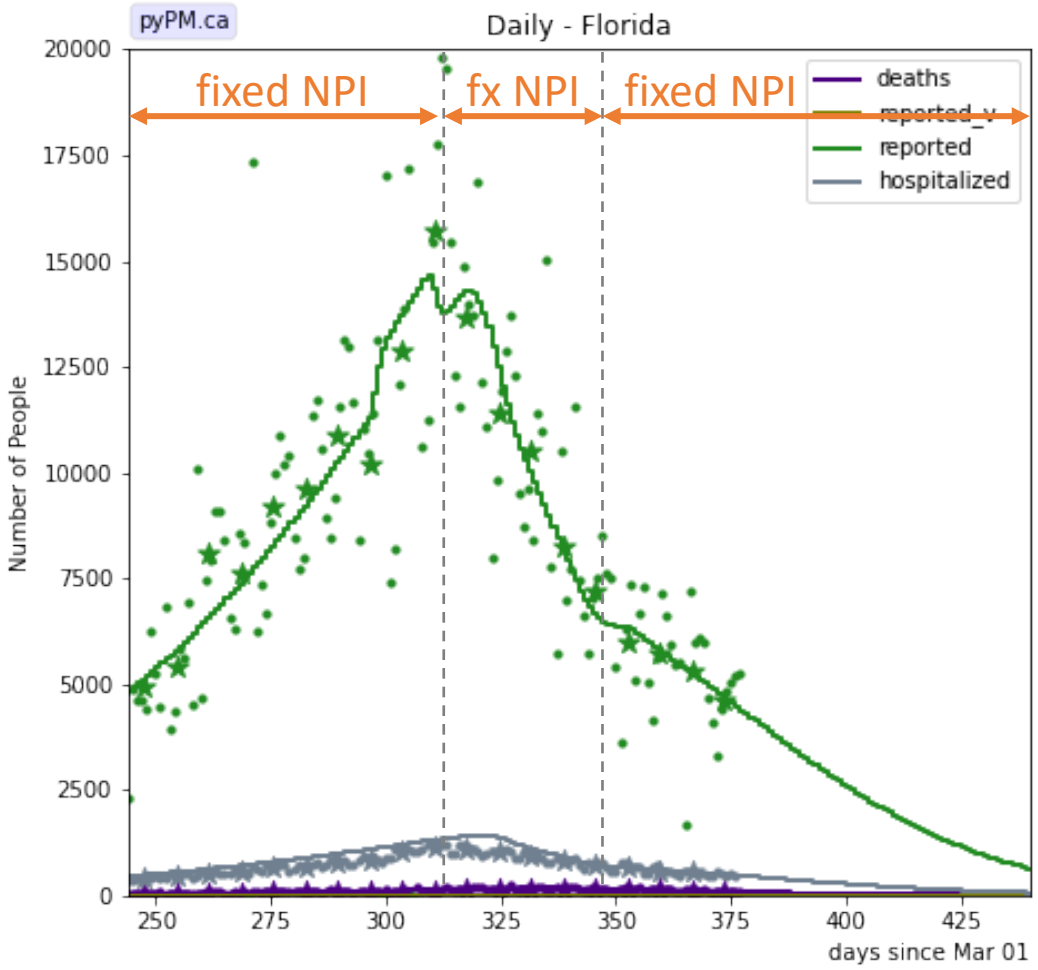
Florida

Data fit with B.1.1.7



Oct 1

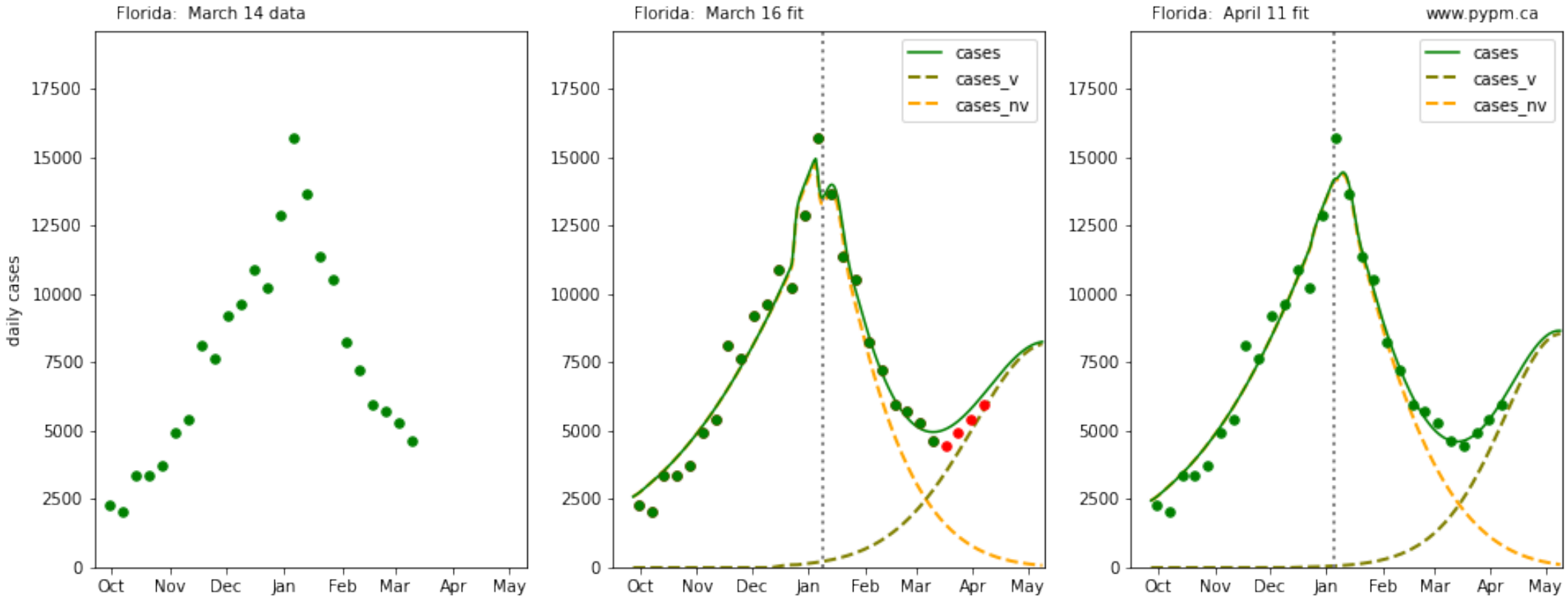
Data fit without B.1.1.7: change in NPI



Oct 1

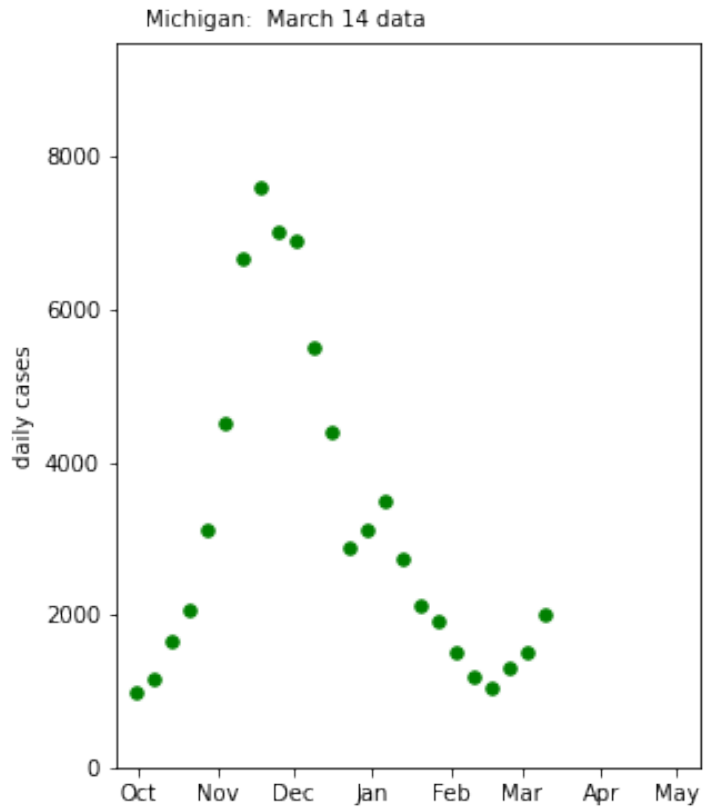
Florida

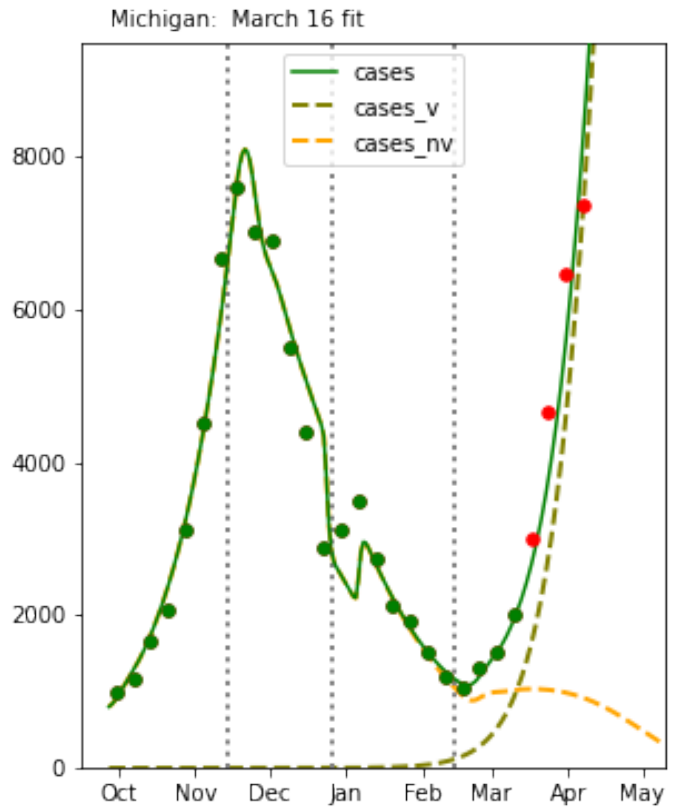
curve: March 16 fit
red points: 4 weeks
data following

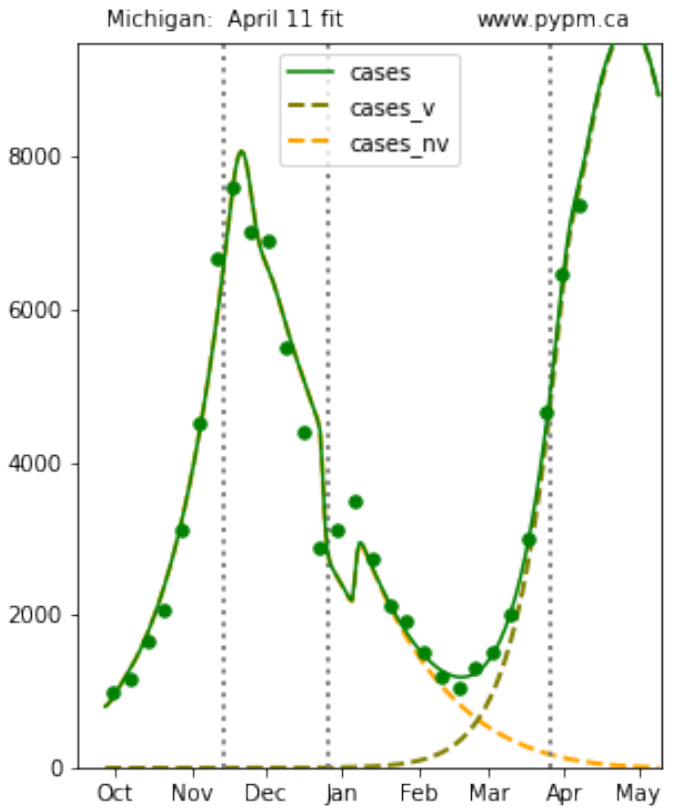


Michigan

curve: March 16 fit
red points: 4 weeks data following



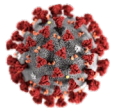




BC Government Assessment of Alpha

- Dr. Bonnie Henry, COVID-19 BC Update, March 18, 2021
  - … “we’re not seeing rapid takeoff with the number of variants. So it’s not like they’re adding onto the cases we’re seeing. What we’re seeing is of the cases, they’re being slowly replaced by this variant”…
  - … “through some of the modelling, looking at what happened in other countries, is that one variant tends to replace what other strains we’re seeing”

- Basic mis-understanding of viral spread
  - BC did not publicly release VoC data in a useful form until later in April
  - BC COVID-19 modelling group decided to begin regular public reports



BC Easter flip-flop

News / Local News

COVID-19: B.C. relaxes rules on worship services in time for Passover, Easter and spring fests

"Some might call it an overreach to not allow singing (when you're outdoors, distanced and masked)," said Darryl Kropp, Northview's board chairman.

Susan Lazaruk
Mar 24, 2021 • March 24, 2021 • 3 minute read • Join the conversation

News / Local News / Local Health / Health

COVID-19: British Columbians urged not to travel, gather during Easter Day long weekend as 832 new cases reported

Leisure trips and getaways that require an overnight stay remain high-risk, said Henry, who encouraged people to stick to day trips within their own communities. "If you are in doubt at all this weekend, just don't go."

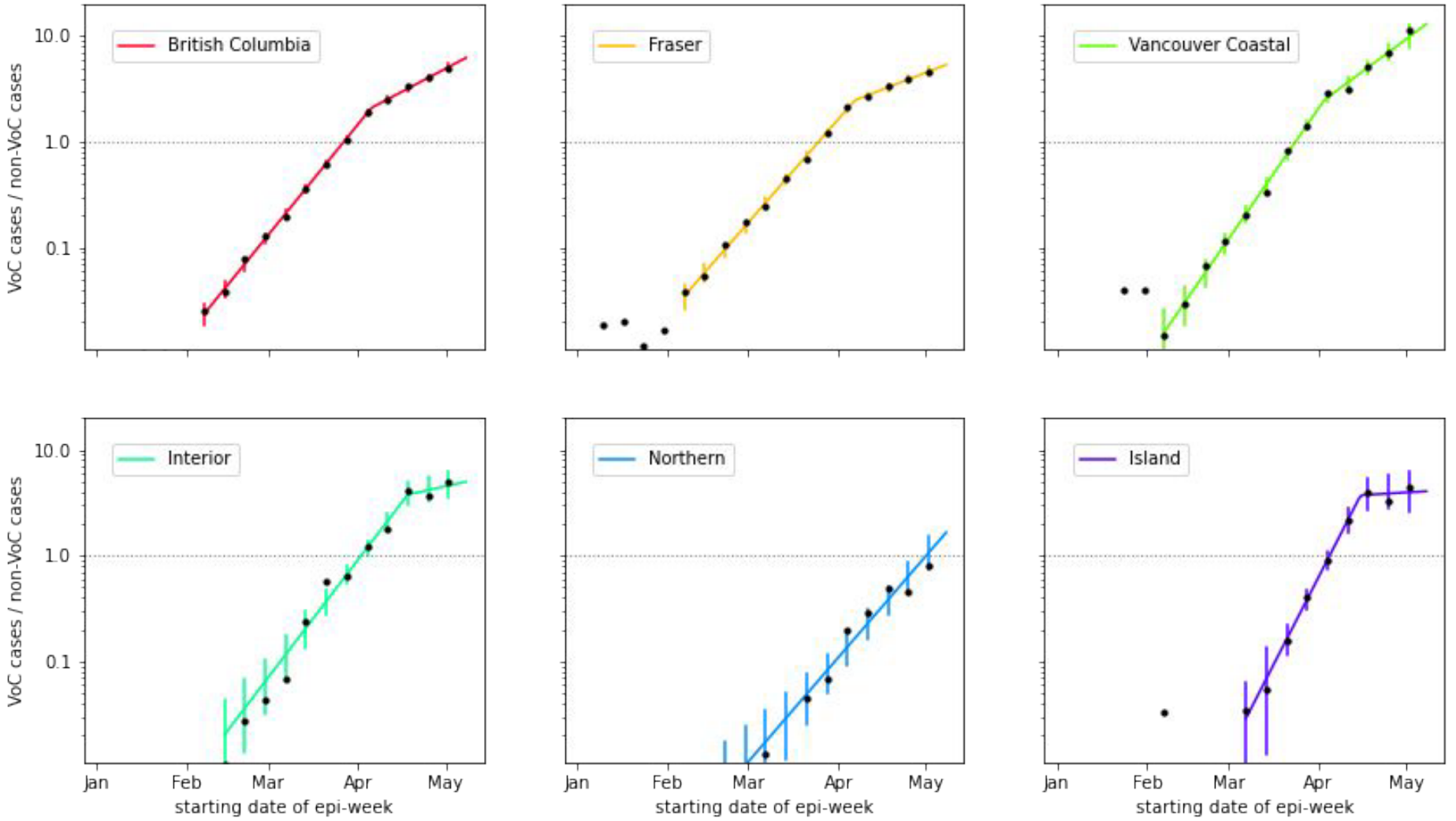
Cheryl Chan
Apr 01, 2021 • April 1, 2021 • 2 minute read • Join the conversation

Growth advantage of Variants of Concern (VoC) in BC

VoC initially grew 8%/day faster than original strains

Became dominant near April 1 (Northern: May 1)

After “circuit breaker”: advantage reduced to 4%/day faster than original strains:
- measures had greater effect on VoC



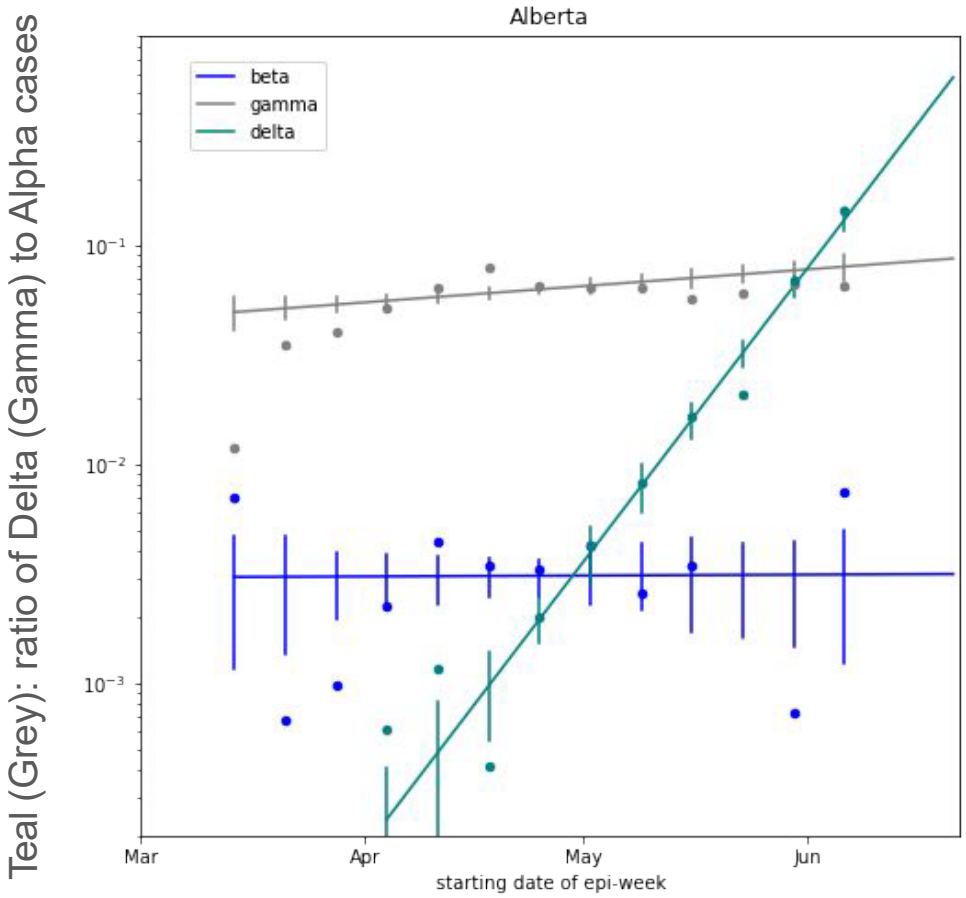
Source (D. Karlen). Fit to weekly VoC and non-VoC case data from BCCDC. Except for Northern HA, a change to the growth advantage is apparent in early April, and fit estimates the change to occur near April 10. There are insufficient data in Interior, Northern, and Island to accurately estimate the change. For details, see Appendix.

The Rise of Delta

Spread of Delta in Alberta

- In Alberta, VOC data are more complete and provided daily, allowing us to estimate a selection coefficient for Delta (B.1.617.2) over Alpha (B.1.1.7):
  - s = 0.10 +/- 0.004 per day (68% CL)
- Currently, Delta accounts for ~20% of current cases in Alberta.
- Delta is estimated to be growing in number:
  - r = 0.026 per day [95% CI: 0.01, 0.043]

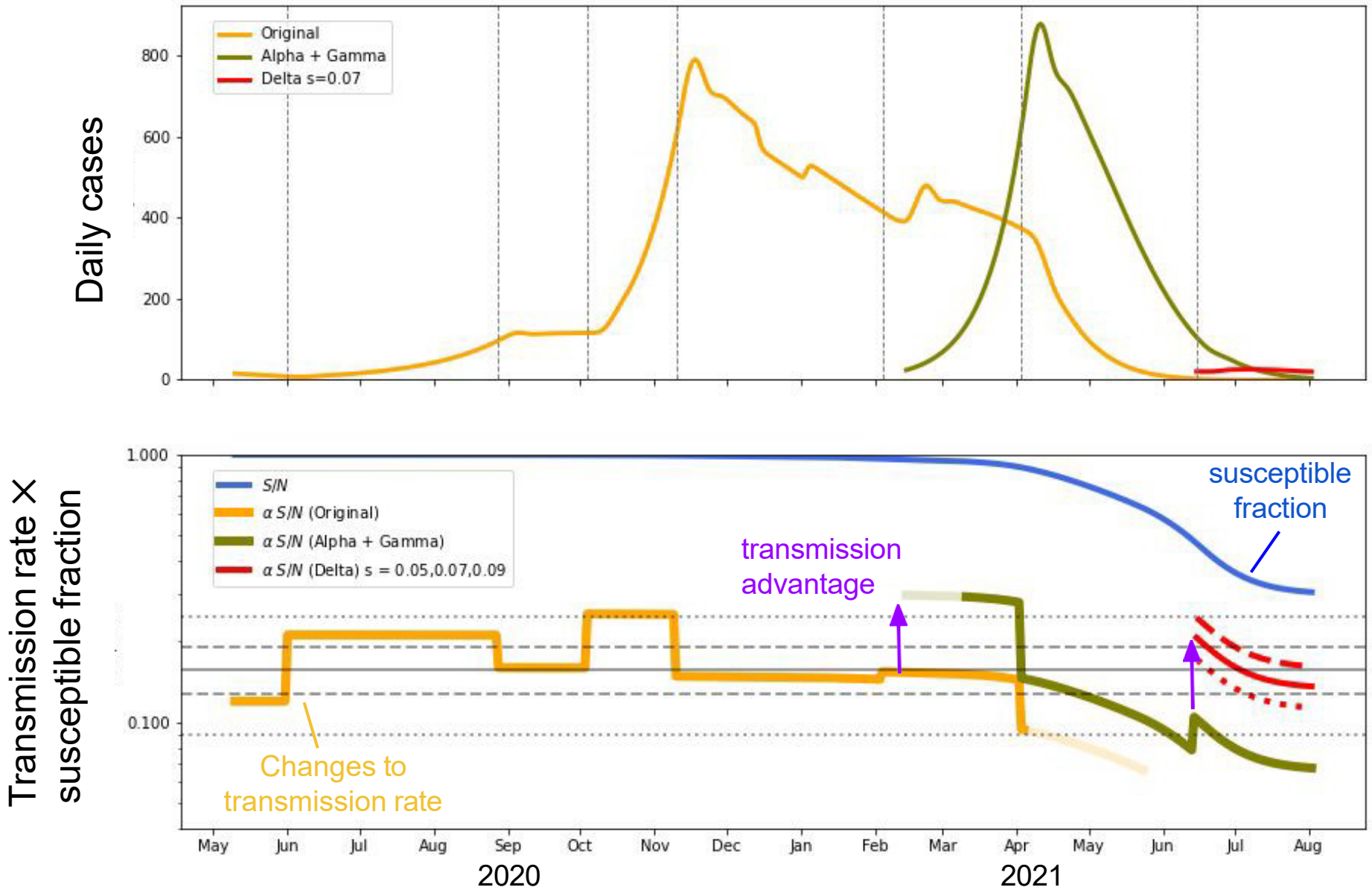
  which corresponds to a 26 day doubling time (95% CI: 16-70 days), even before the recent reopening.



CAVEATS: Analysis does not account for future vaccinations. Labs in Alberta have recently gone back through and typed past samples for Delta. Critically, *this analysis assumes that the back-typing is nearly complete for Delta.*

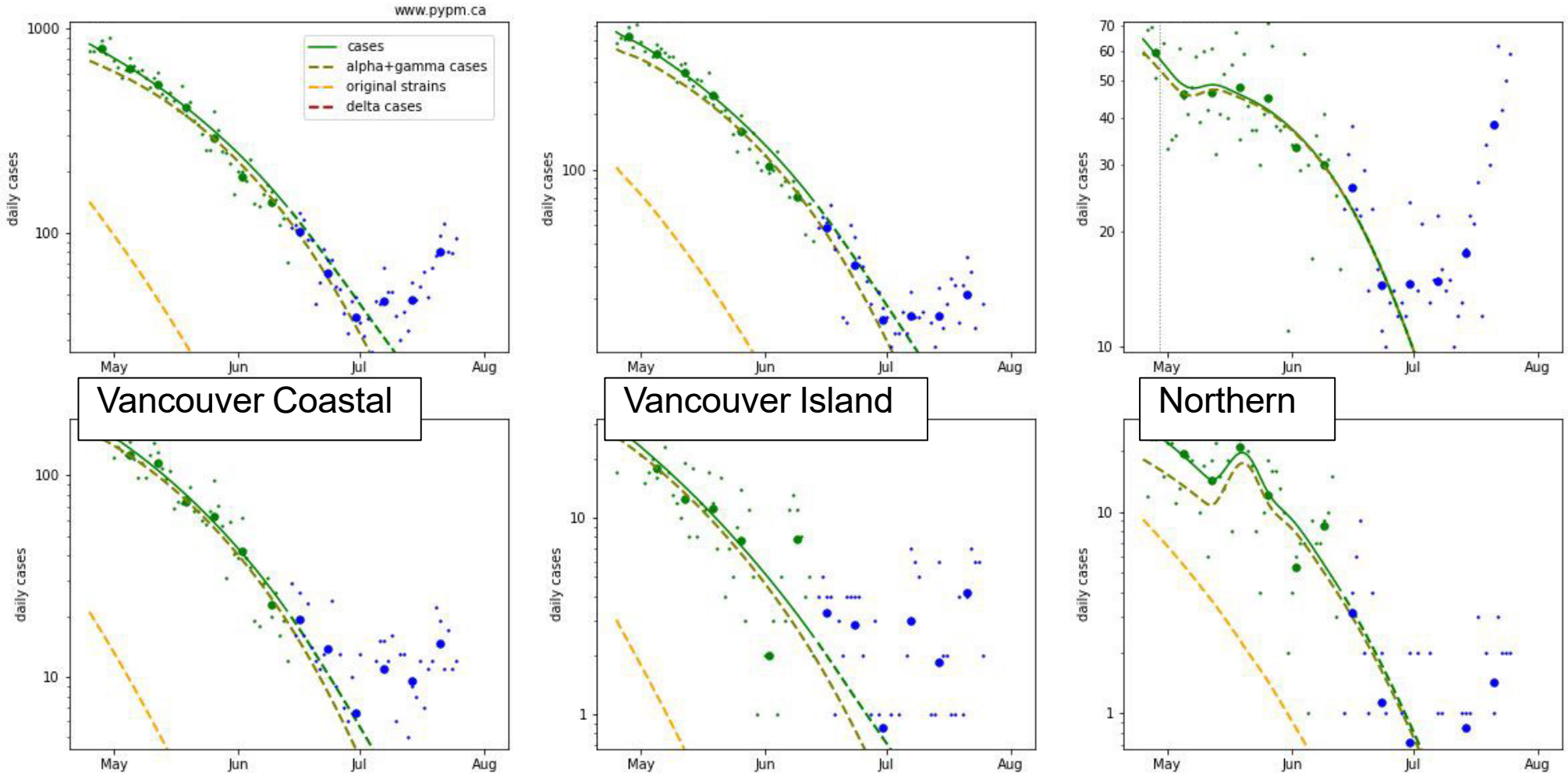
Source (S. Otto and Dean Karlen). Data from source file https://www.alberta.ca/stats/covid-19-alberta-statistics.htm#variants-of-concern (accessed June 14, using data through June 7). The estimate of the growth rate (*r*) depends on an inference of sampling fraction in May, which was based on a fit of the total proportion of all VOC from April 10 to June 7, 2021.

Past and future growth



Source (D. Karlen). See www.pypm.ca. These plots illustrate how transmission rate and susceptible fraction combine to determine the growth rate.

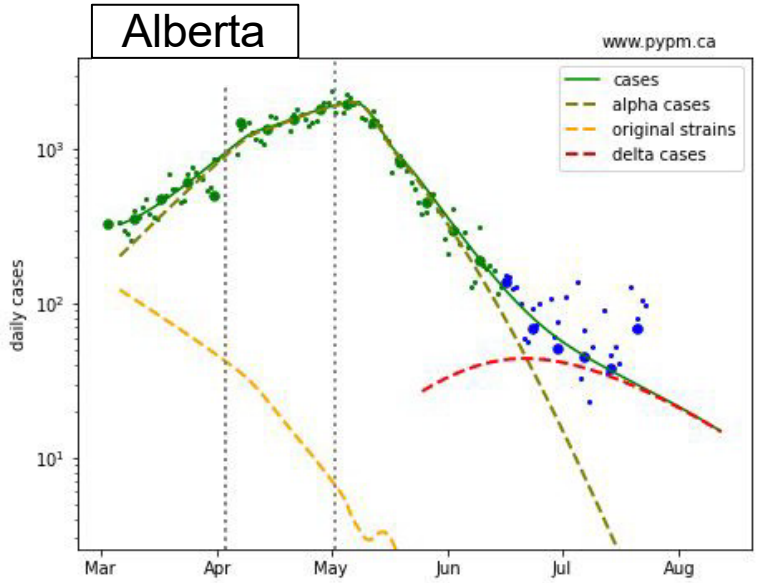
June 16 model fit, showing recent data (log scale)

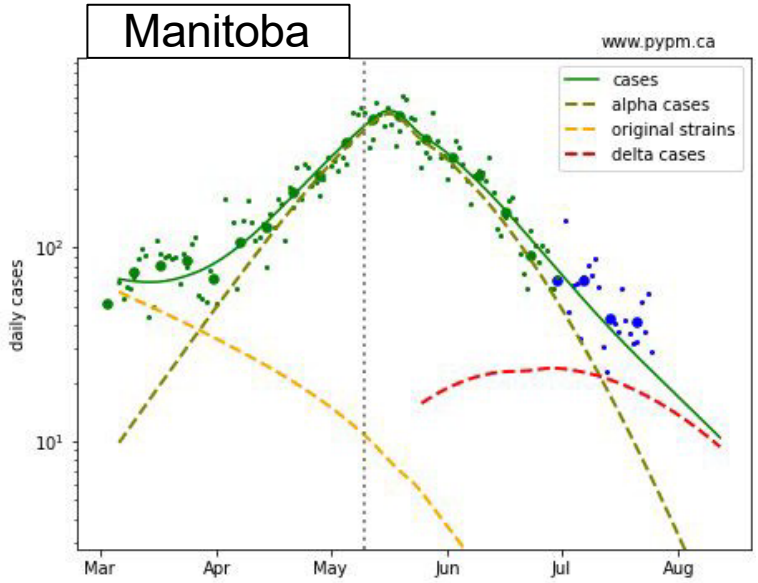


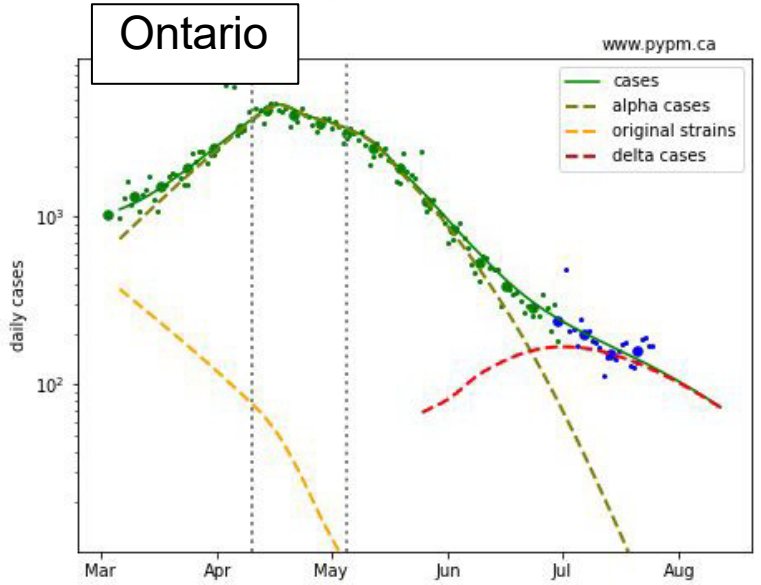
Soon after Step 3 of reopening (July 1), case rates began to rise above June 16 model projections.

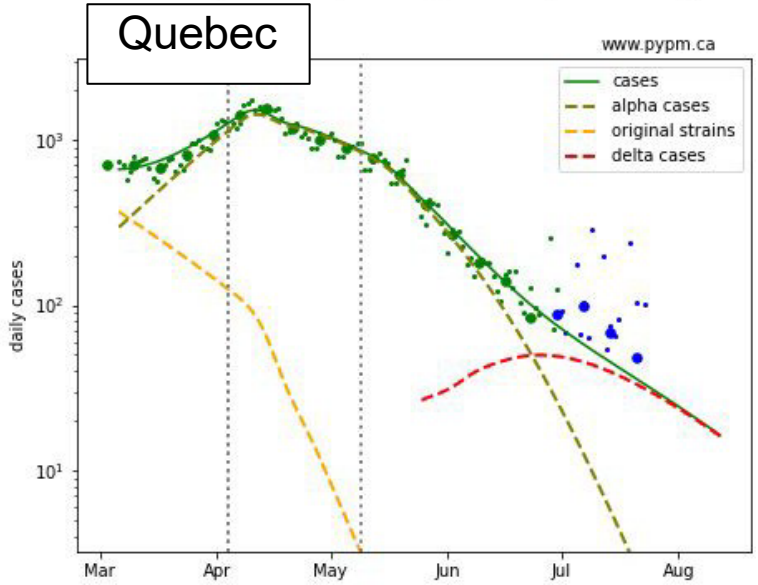
Source (D. Karlen). See www.pypm.ca. These models have no age structure. Fits include past vaccination schedule. Assumes 1st+2nd dose effectiveness rises over time to 90% (see May 14 report for details). Vaccination model benchmarked with data from Israel: see link. Assumes transmission rates are constant May-August.

Earlier model fits for other provinces, showing recent data







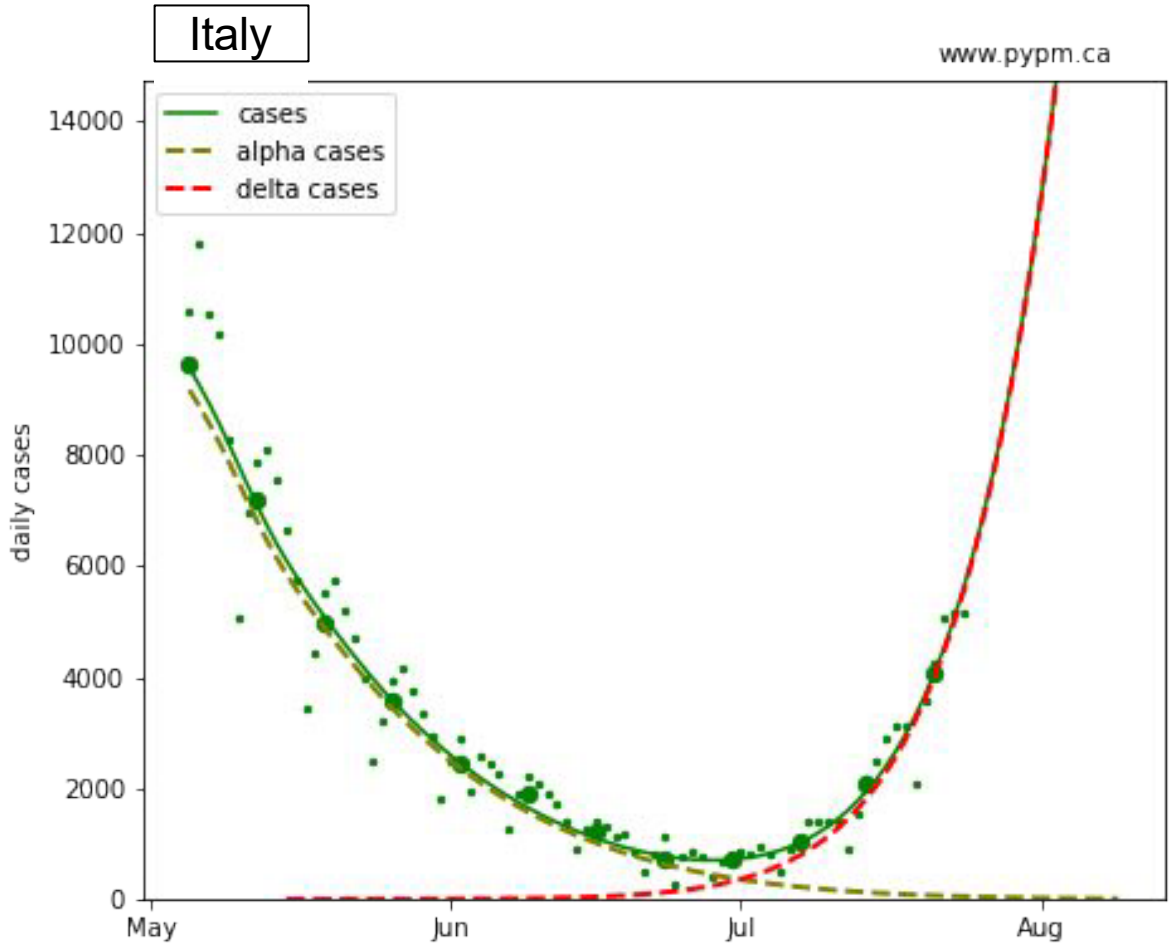


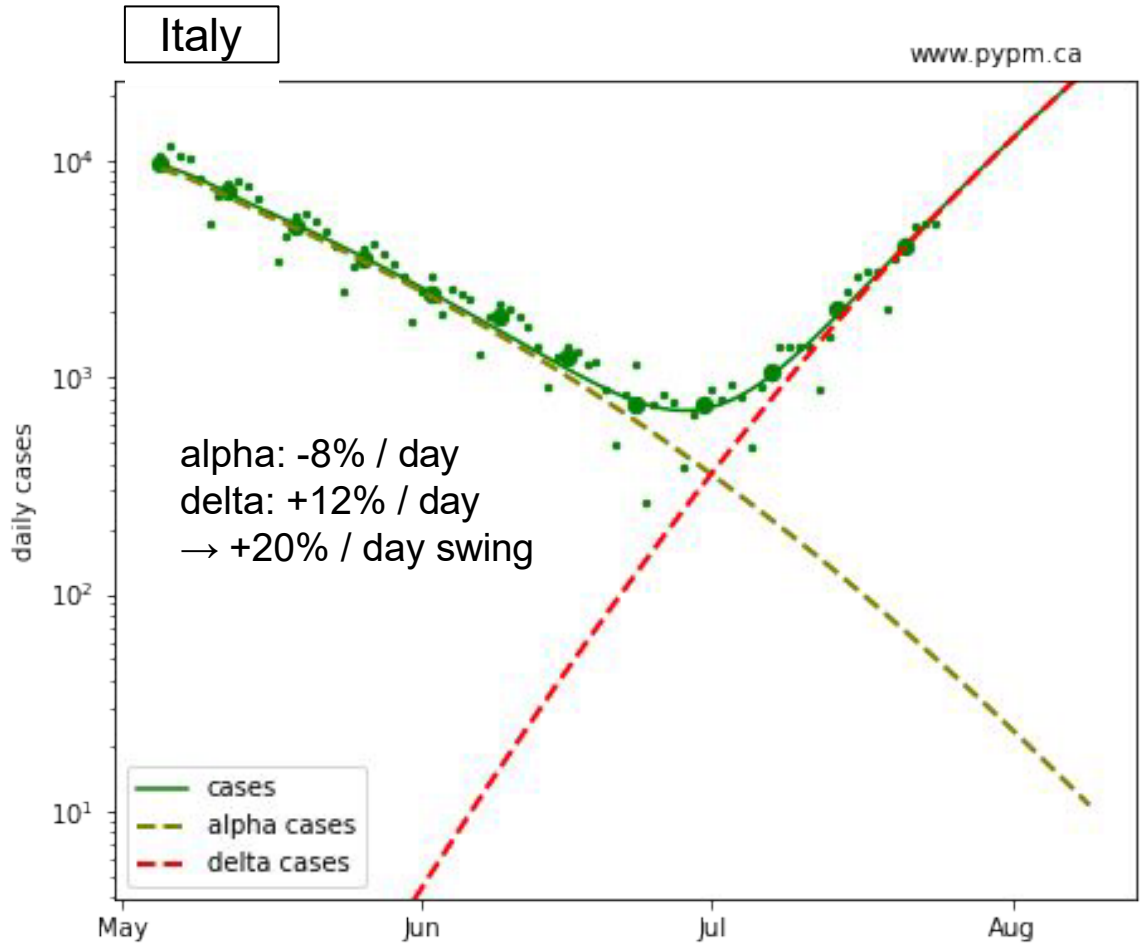
Recent data are compared to earlier model projections for 4 provinces.

The decline in case rates agree with the projections from a month earlier, with the exception of Alberta, where a significant uptick in case rate is seen in the past week.

Source (D. Karlen). See www.pypm.ca. These models have no age structure. Fits include past vaccination schedule.

Example of current rapid growth: Italy

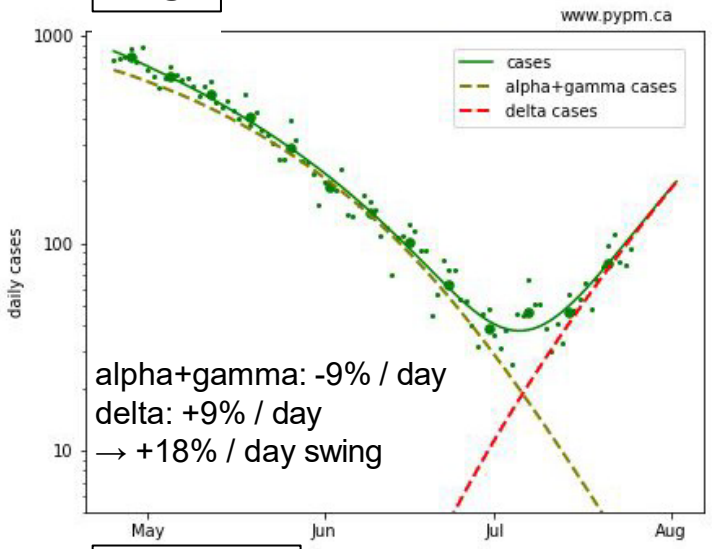




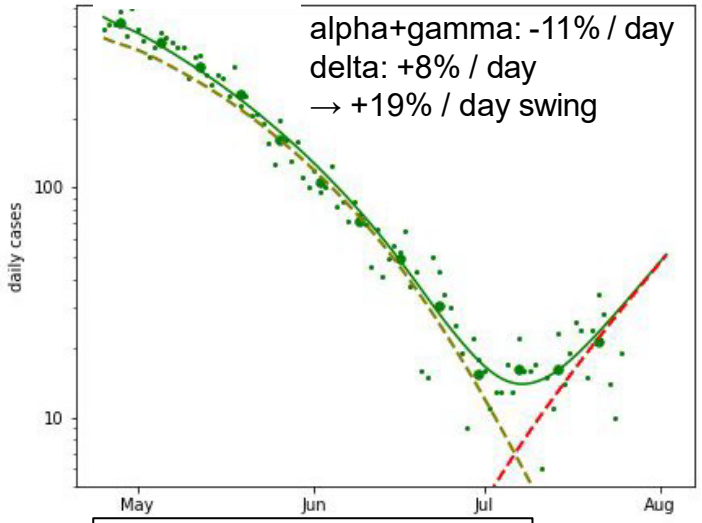
Source (D. Karlen). See www.pypm.ca for model fits to US state and EU nation case data. These models have no age structure. Fits include past vaccination schedules.

Model fits with recent BC data

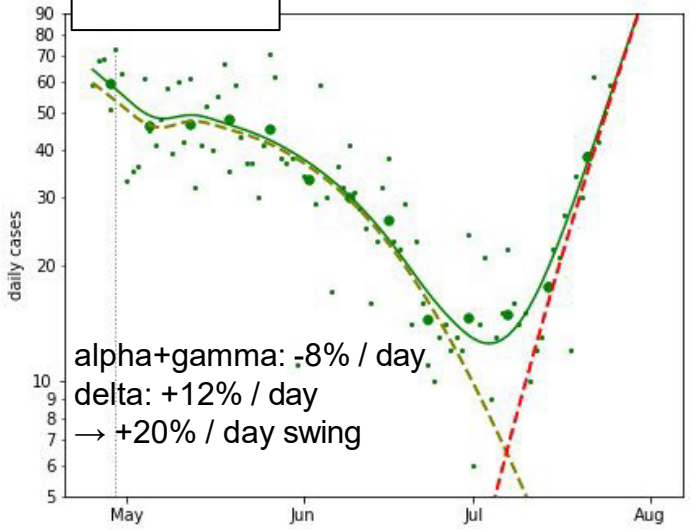
BC



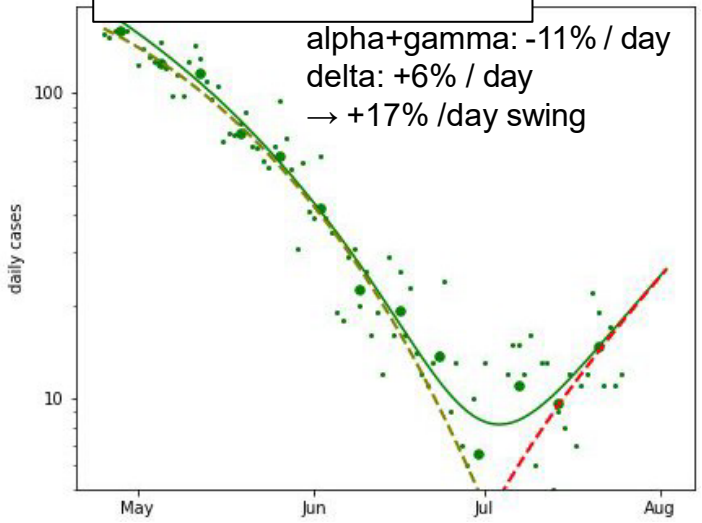
Fraser



Interior



Vancouver Coastal

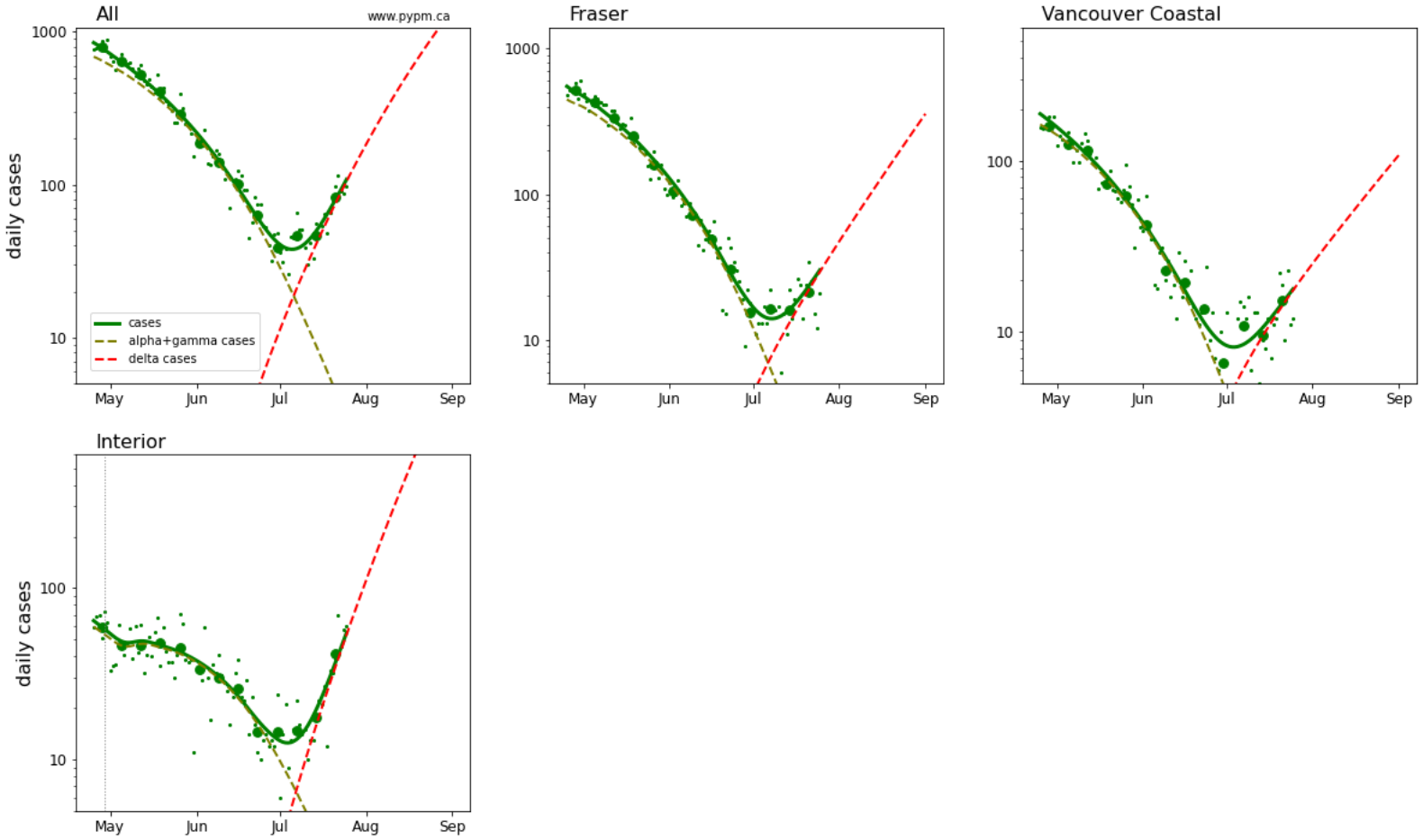


BC data fits are consistent with the pattern seen in Europe and US states, where the combination of relaxation and the emergence of delta has produced large swings in daily growth rates.

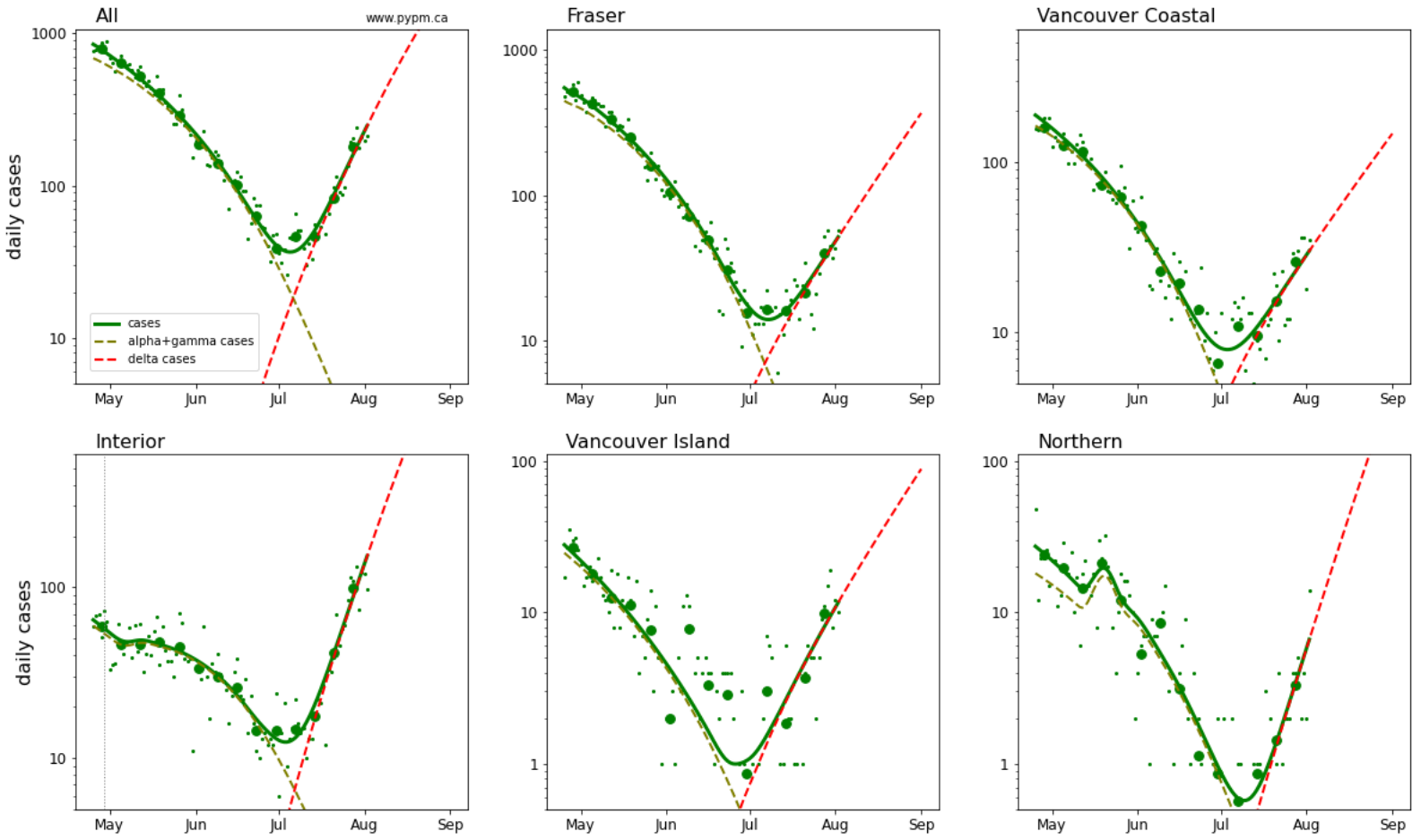
The proportion of cases due to delta may differ from these fits since the fits assume constant behaviour.

Source (D. Karlen). See www.pypm.ca. These models have no age structure. Fits include past vaccination schedule.

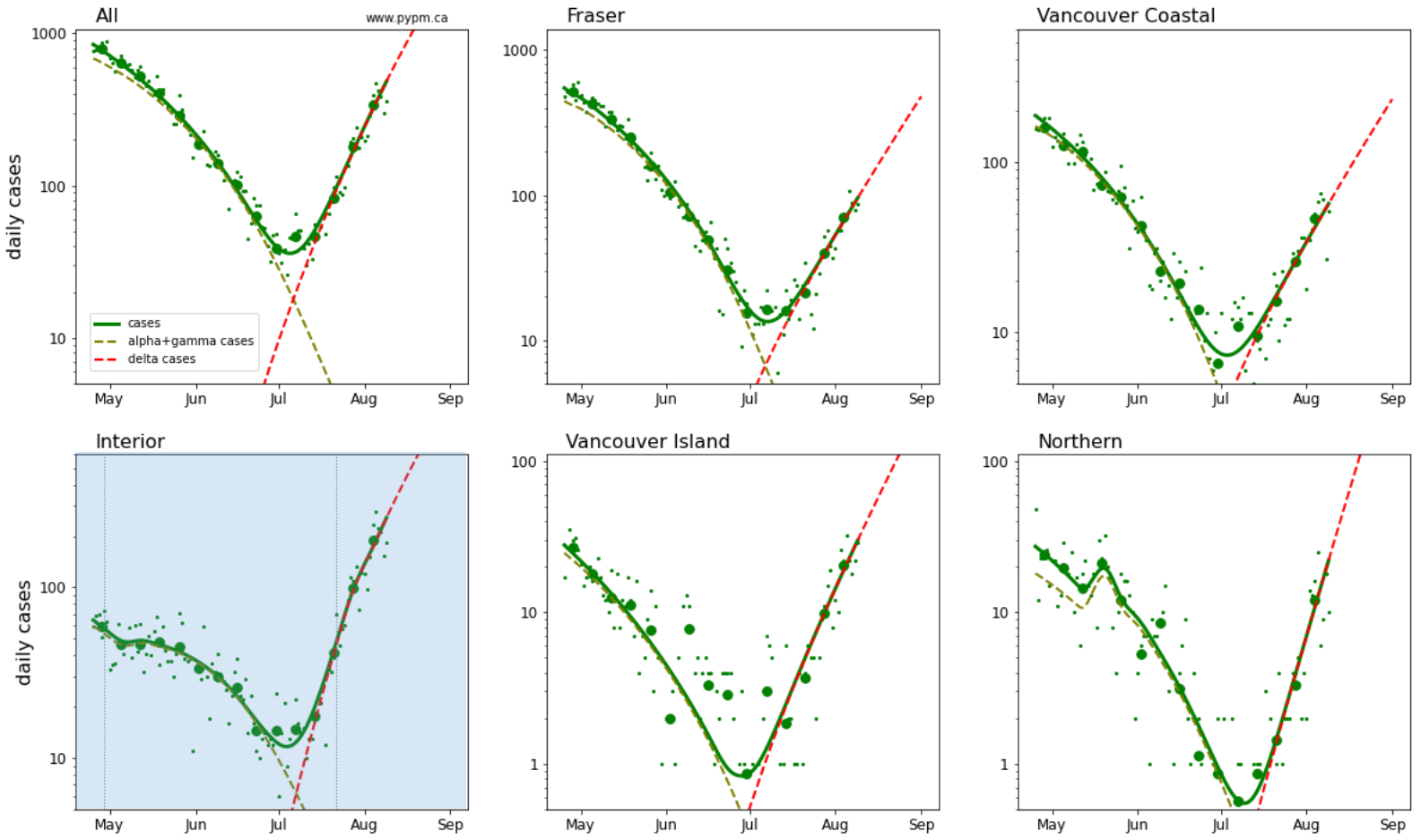
2021-07-26 forecast



2021-08-03 forecast

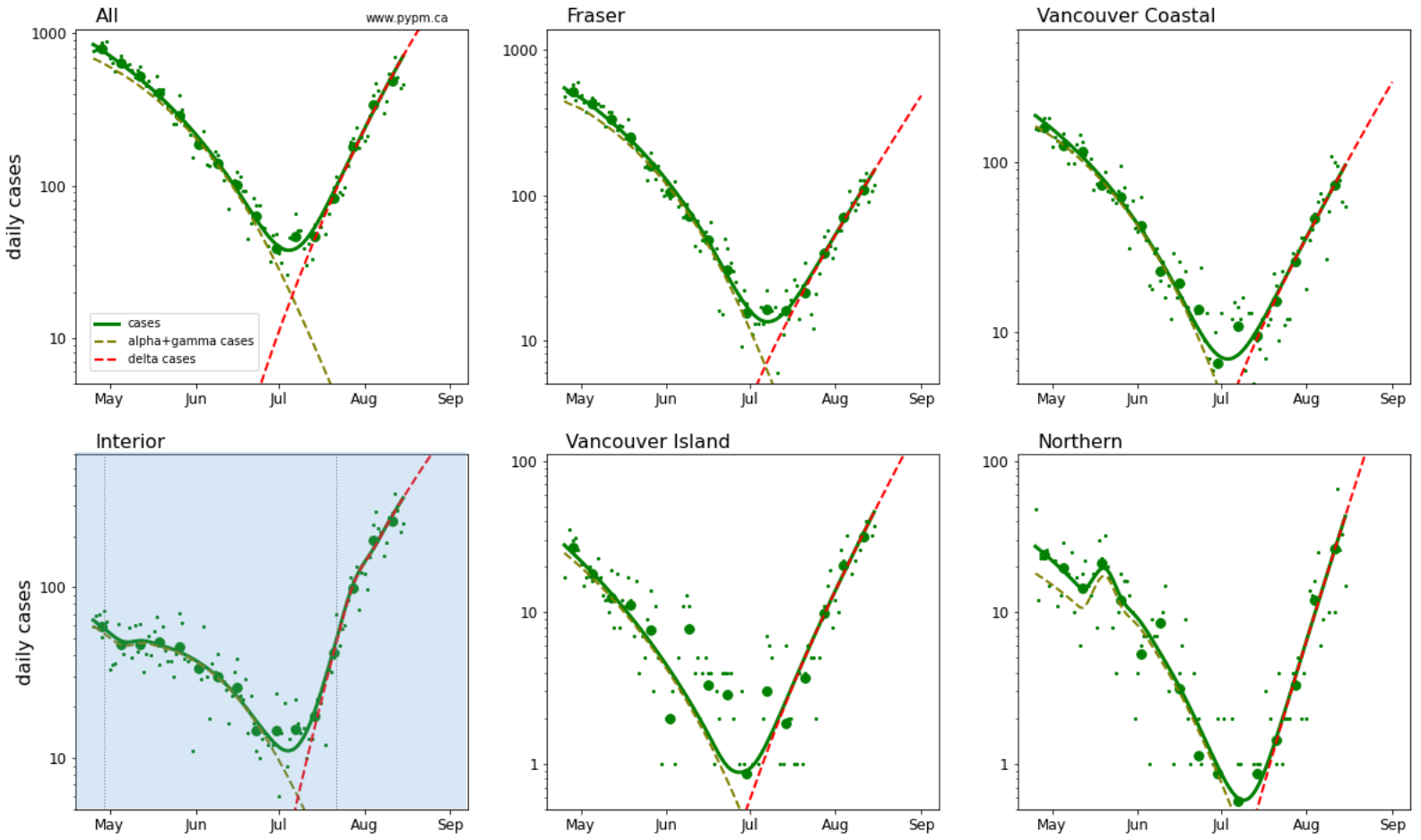


2021-08-10 forecast



New measures for Interior Health flattens the curve

2021-08-16 forecast



New measures for Interior Health flattens the curve

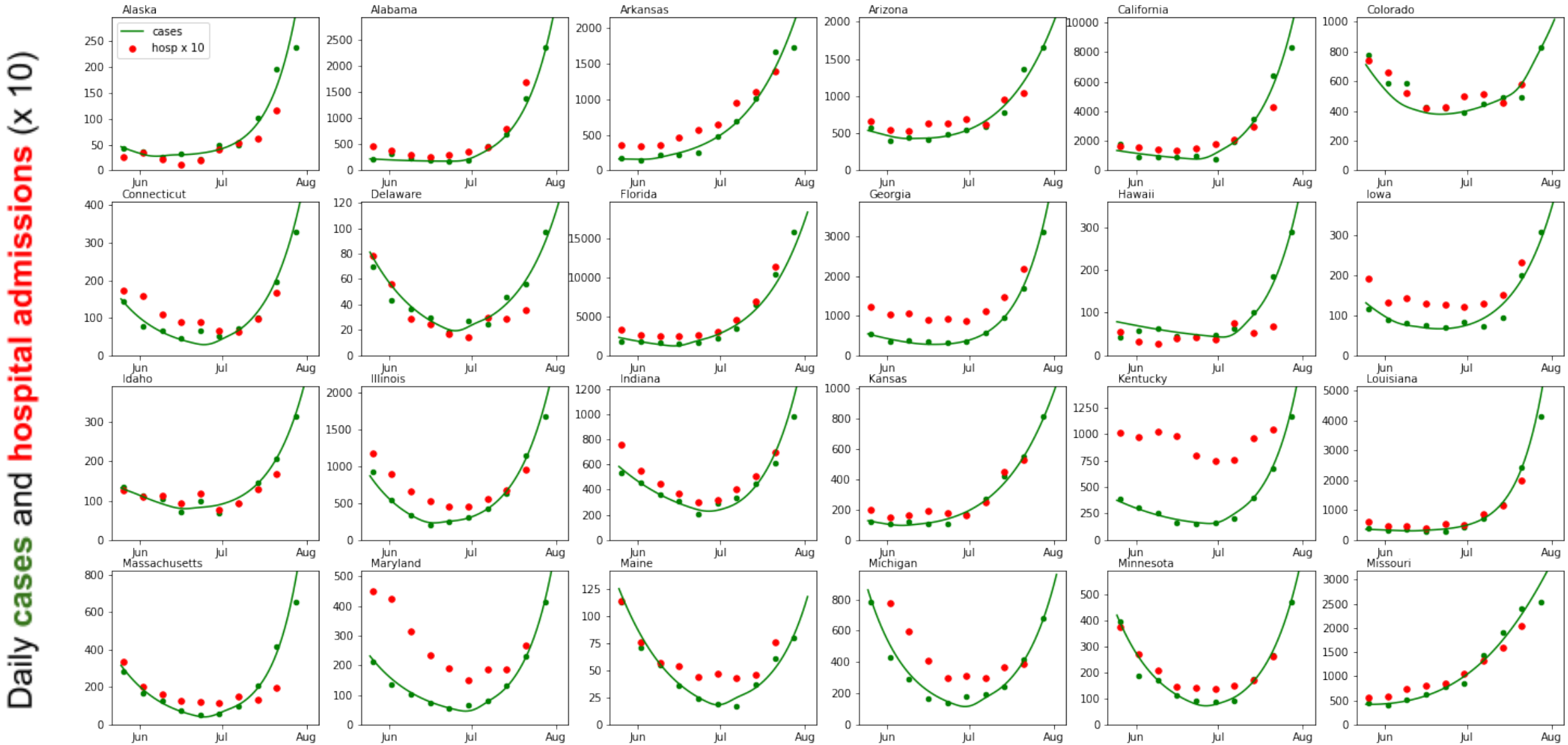
BC Government Assessment of Delta (Aug 12)

- Reporter question: “Why isn’t stronger action required for all of BC now given that the rolling average of cases outside the interior has been quadrupling in the past few weeks?”

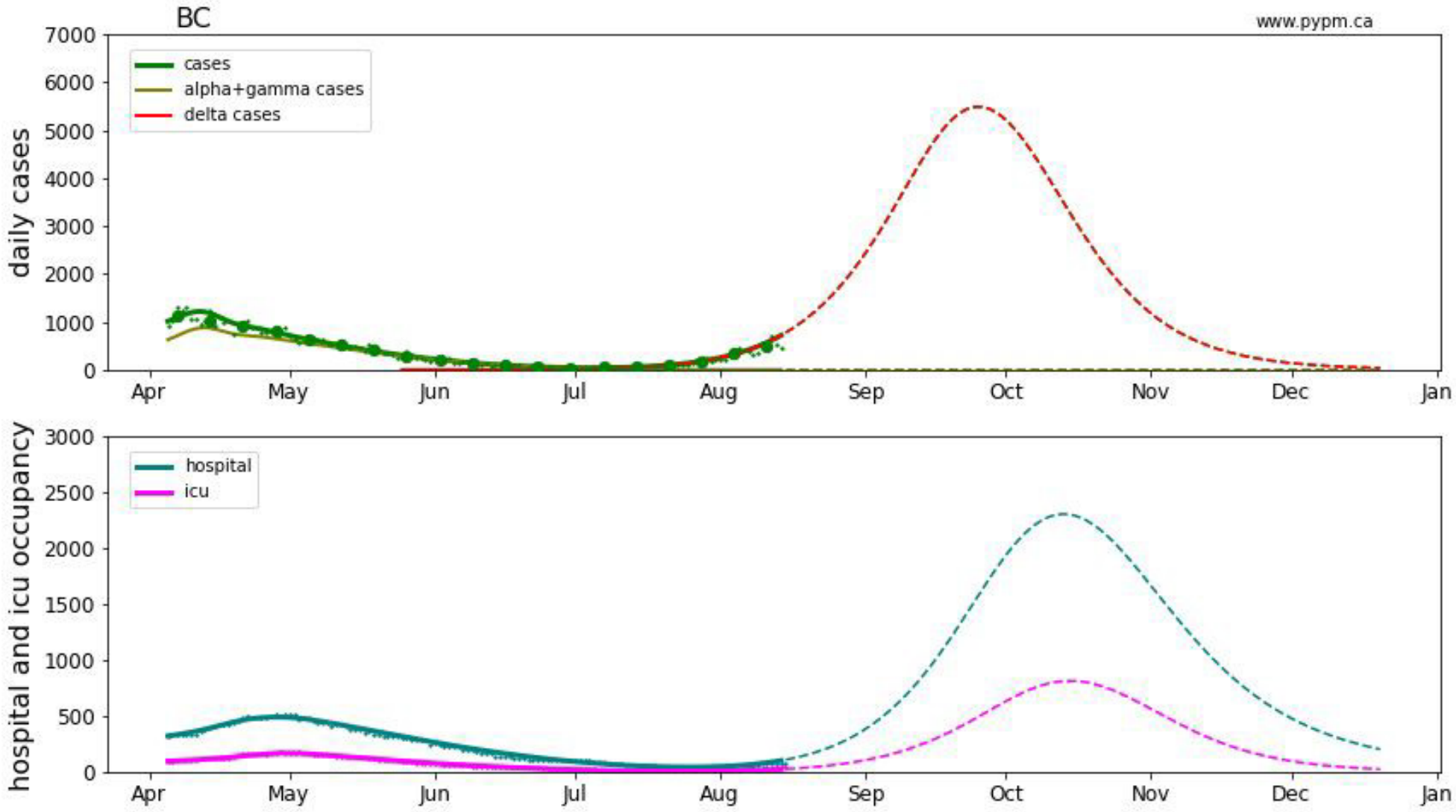
- Dr. Bonnie Henry:
  - “When we put out the 3 step plan we understood that we’re in a different place, when we have most people protected by immunization. So it means that we are decoupling the hospitalizations and deaths from the cases themselves.”
  - “There are a couple of places around the provinces where we’ve seen spikes, they are often related to a single event. We are seeing different types of patterns in different parts of the province. Right now we feel that we don’t need to take additional measures across the board, for sure.”

Hospitalization rates rise with cases (USA)

US is in a Delta wave, and hospital admissions (red) are rising with increasing case rates (green), despite high vaccination levels.



Longer term projection (expansion of vaccine coverage)

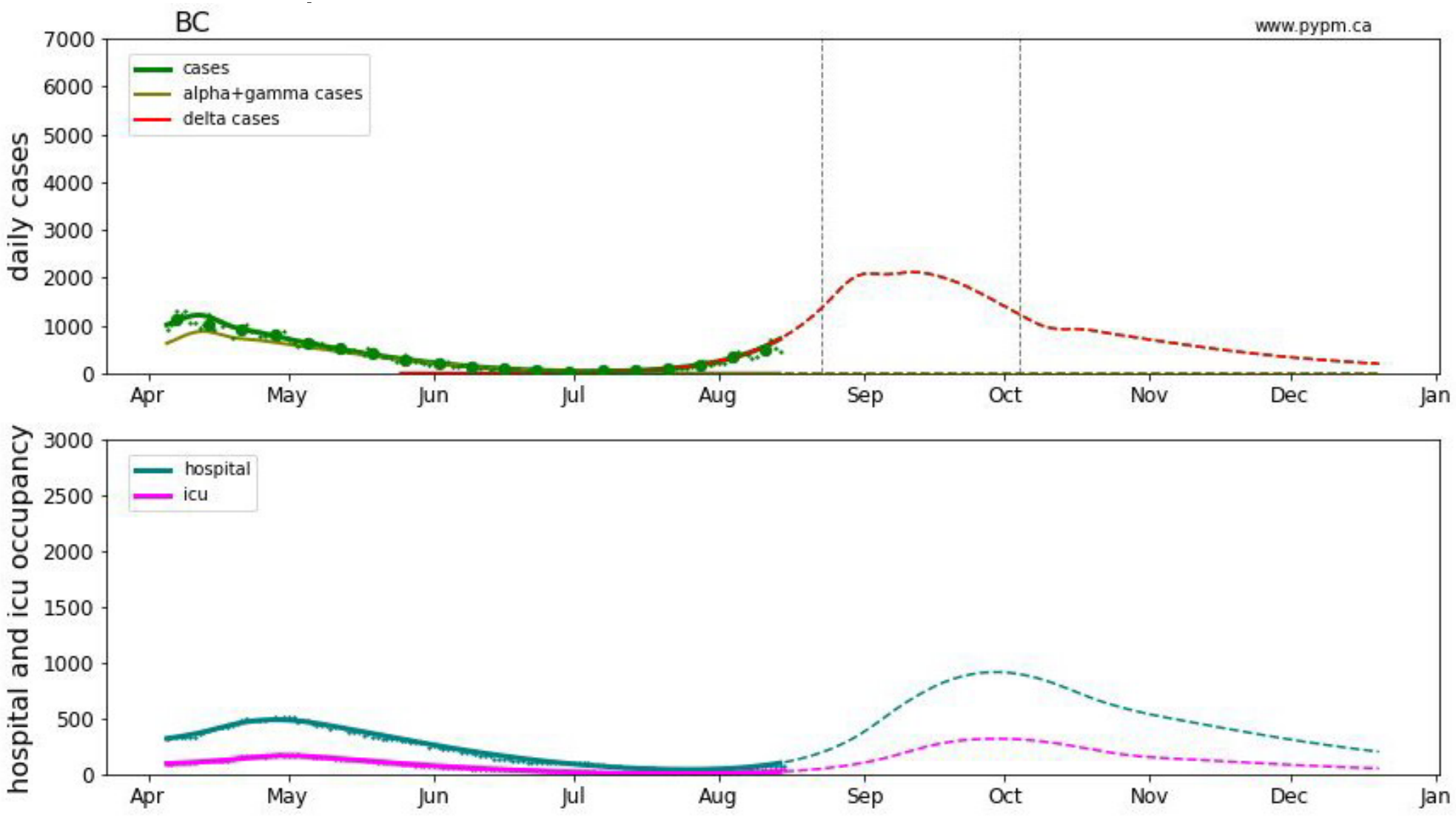


In this scenario, first dose vaccinations increase by 20,000 per day starting next week until 90% of population is vaccinated.

Due to the delay in gaining vaccine immunity, the peak hospital demand remains unacceptable.

Source (D. Karlen). See www.pypm.ca. These models have no age structure. Fits include past vaccination schedule. Assumes 90% of total population vaccinated.

Longer term projection (measures and vaccine expansion)

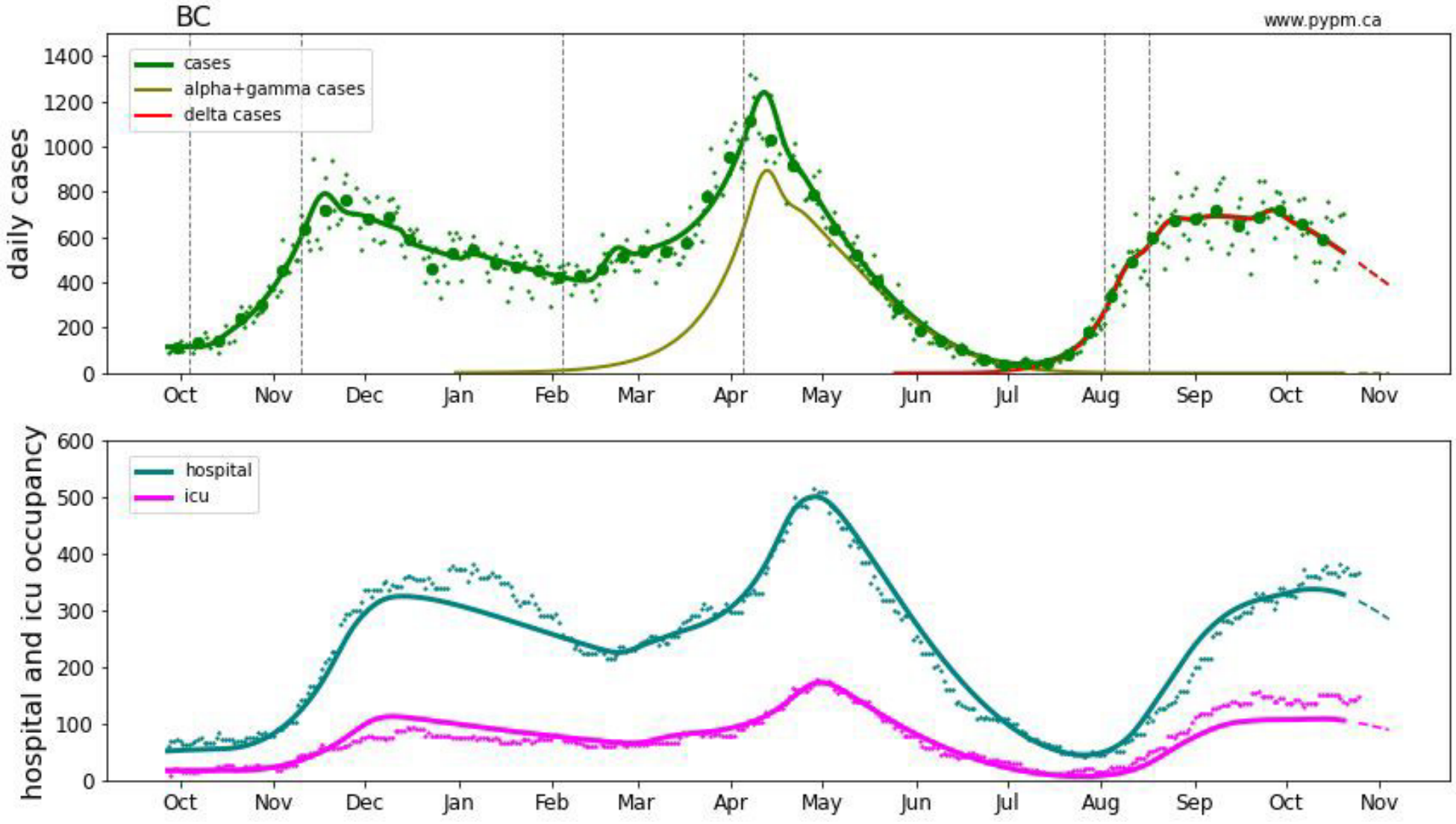


In this example, measures enacted next week stop the growth of delta, while vaccine immunity builds. Measures are rescinded after six weeks.

While demands exceed previous levels, they are reduced compared to the vaccination only scenario.

Source (D. Karlen). See www.pypm.ca. These models have no age structure. Fits include past vaccination schedule. Assumes 90% of total population vaccinated.

BC brings back province-wide mask order: August 24



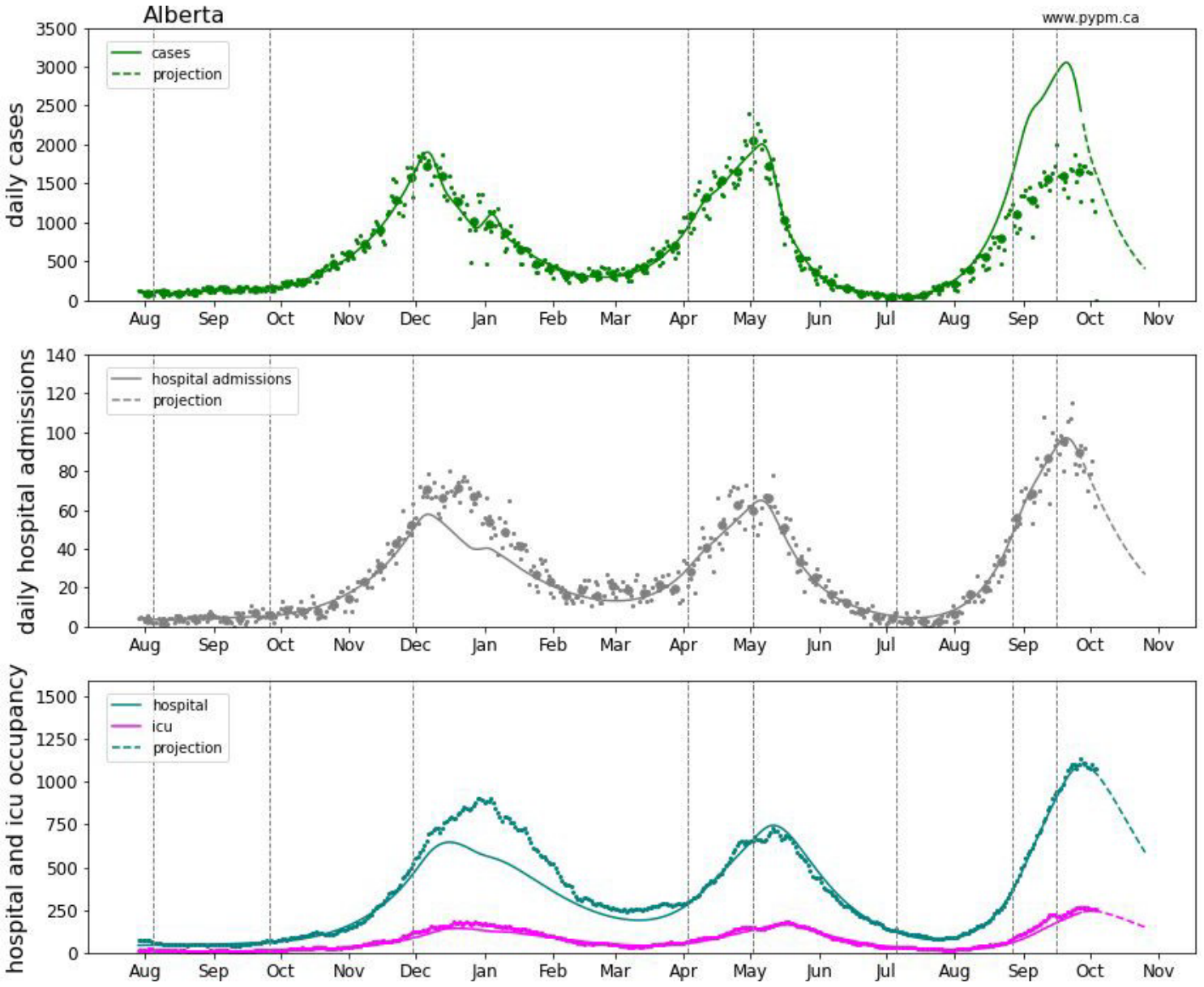
The COVID-19 pandemic is tracked using positive tests (cases), yielding an infection model (green curve).

The infection model well describes past hospital occupancy.

Recent hospital and ICU occupancies exceed projections calibrated by data from the third wave.

Source (D. Karlen). See www.pypm.ca. These models include vaccination but have no age structure.

Alberta delayed action by a month…



Fits hospital admission data (grey) rather than case data.

Finds that many more cases would have been reported had testing practice not changed.

Significant reversal in growth is apparent. Fitted date for change to transmission rate: Sept 15.

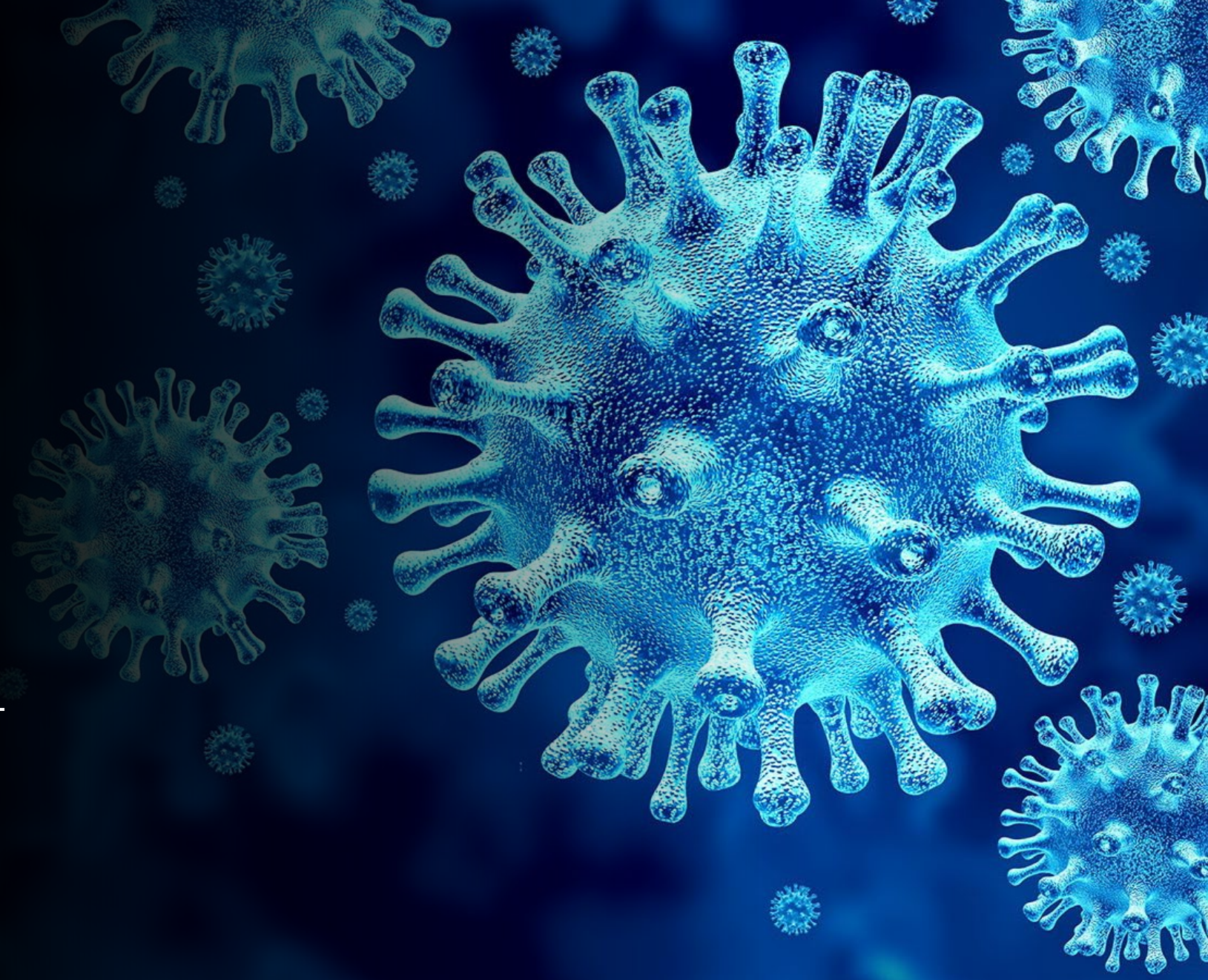
(Note: projections for recent changes have large uncertainty.)

Hospital and ICU occupancy data now in agreement with model for 3rd and 4th waves.

Hopeful sign for the future!

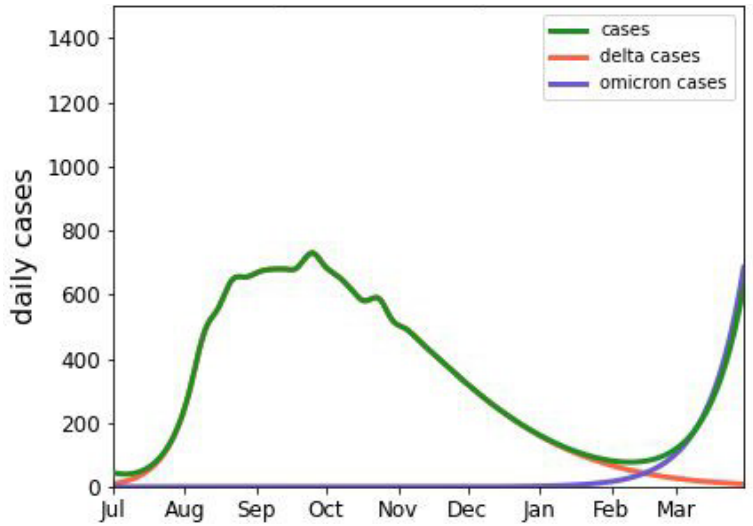
Source (D. Karlen): COVID-19 Alberta Statistics, www.pypm.ca

The Rise of Omicron

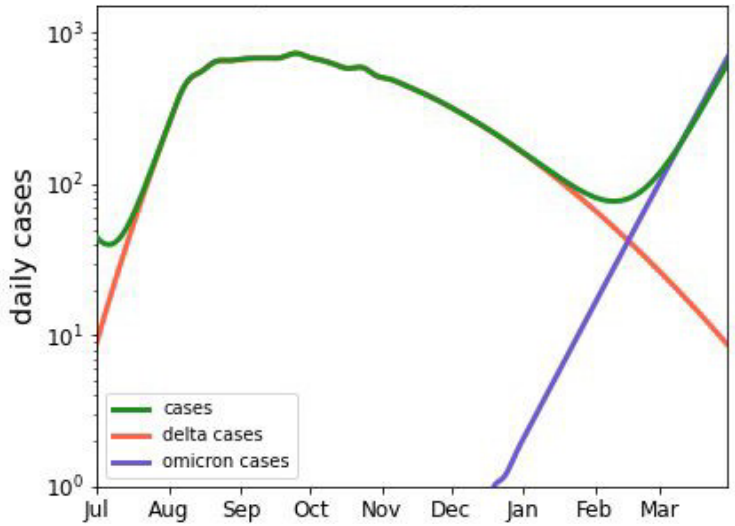


BC projections for Omicron with daily growth of 7% and 17%

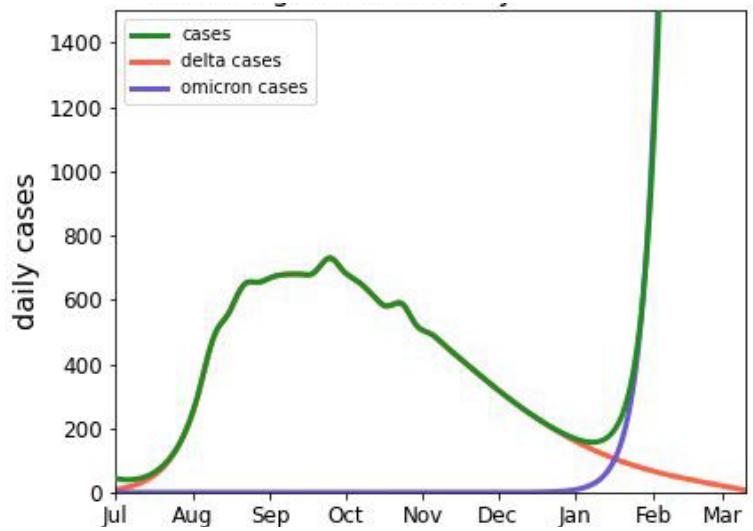
7% (linear scale)



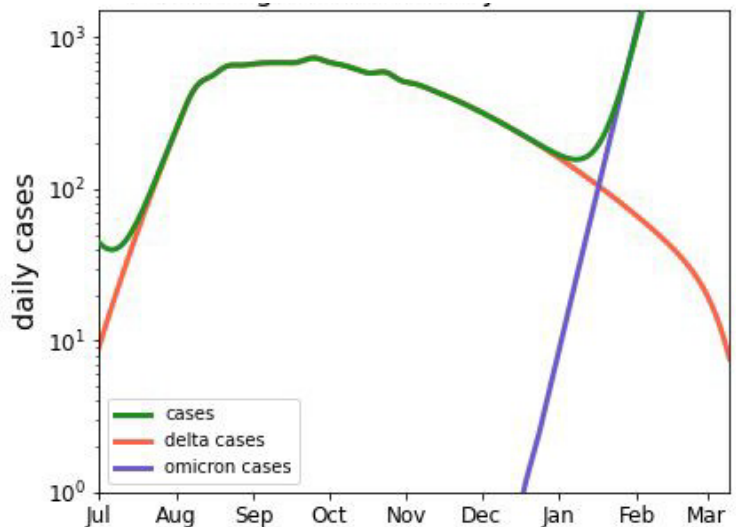
7% (log scale)



17% (linear scale)



17% (log scale)



Model assumptions:

- Maintain current health measures
- Community transmission of Omicron starting in mid-December

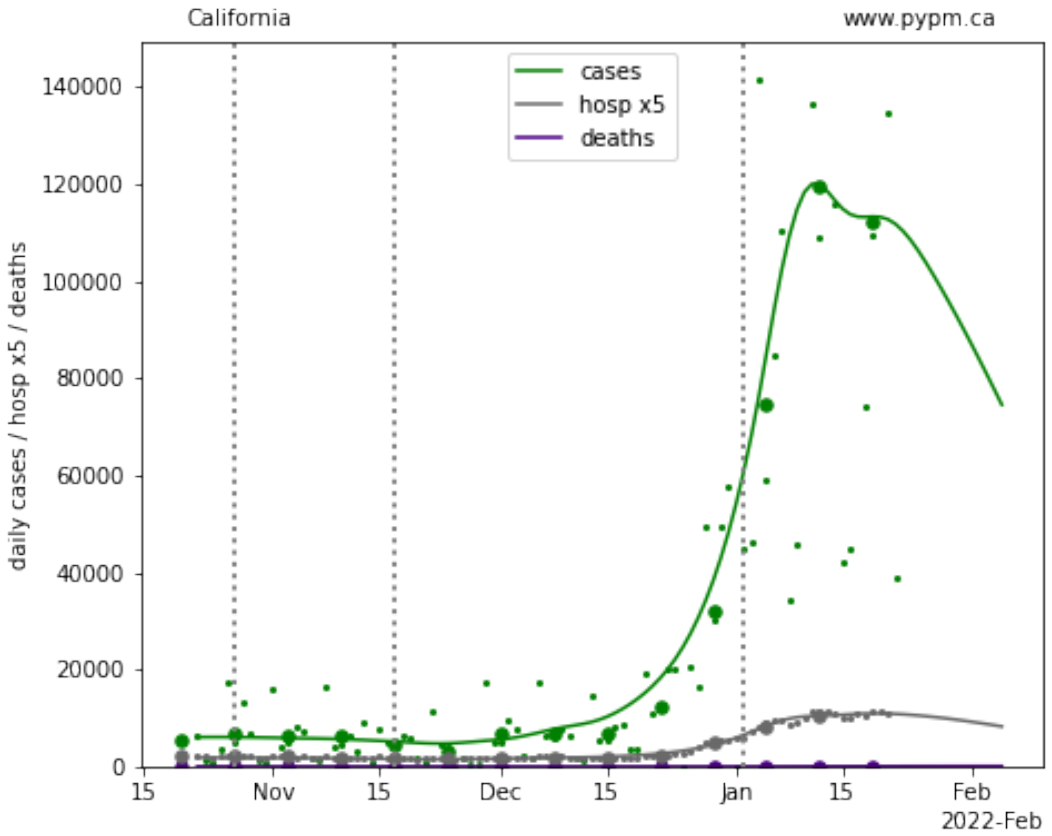
Findings:

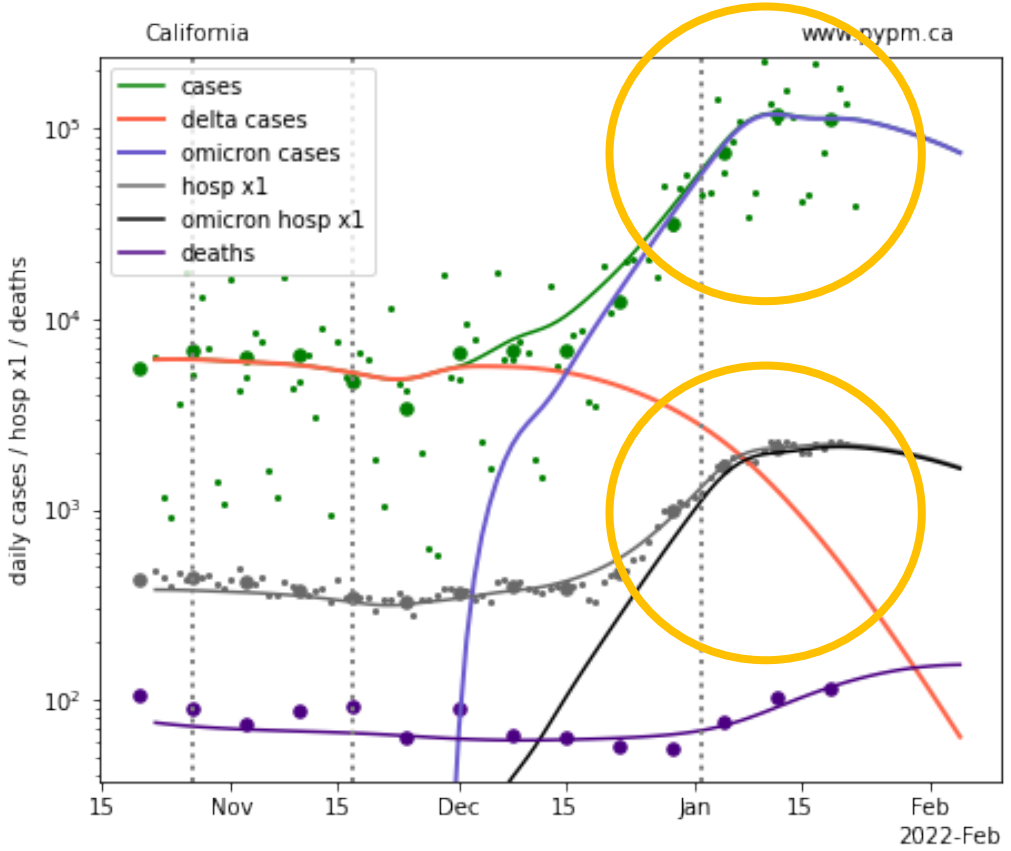
- 7% daily growth would be similar to the start of the fourth wave (July/August)
- 17% daily growth would give little time to respond with additional measures

The fraction of cases leading to hospitalization and deaths is unknown. If unchecked, health care demands will grow rapidly, as seen in South Africa.

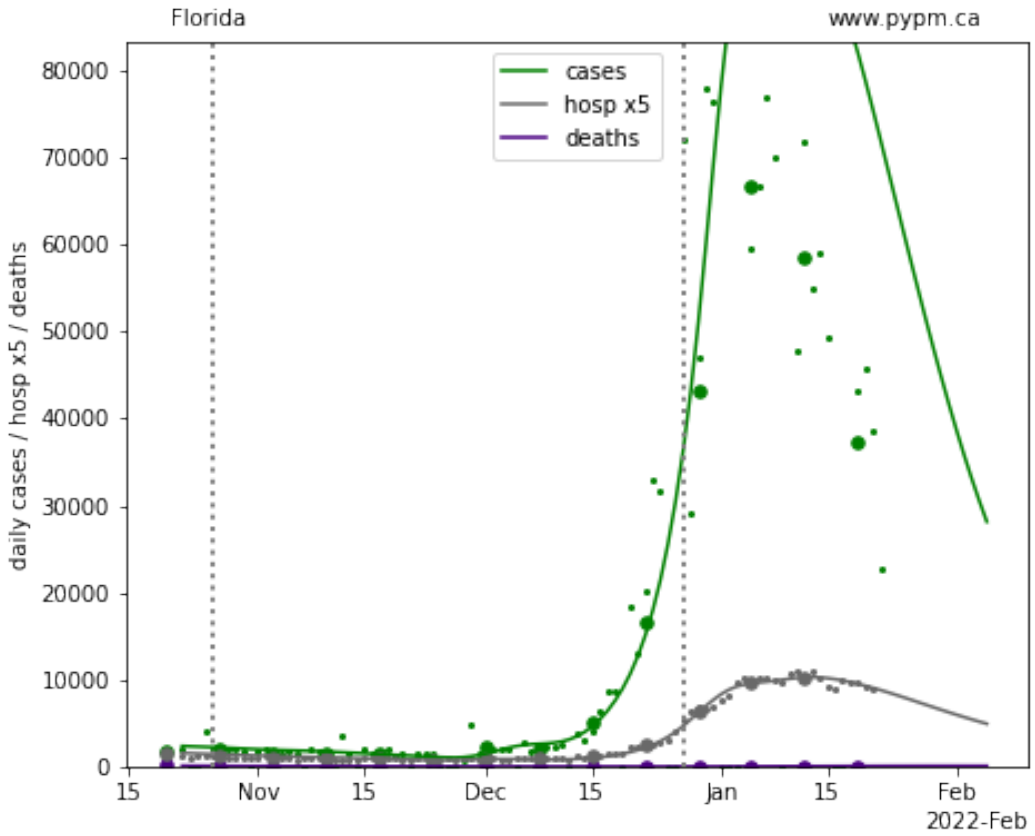
Source (D. Karlen). See www.pypm.ca.

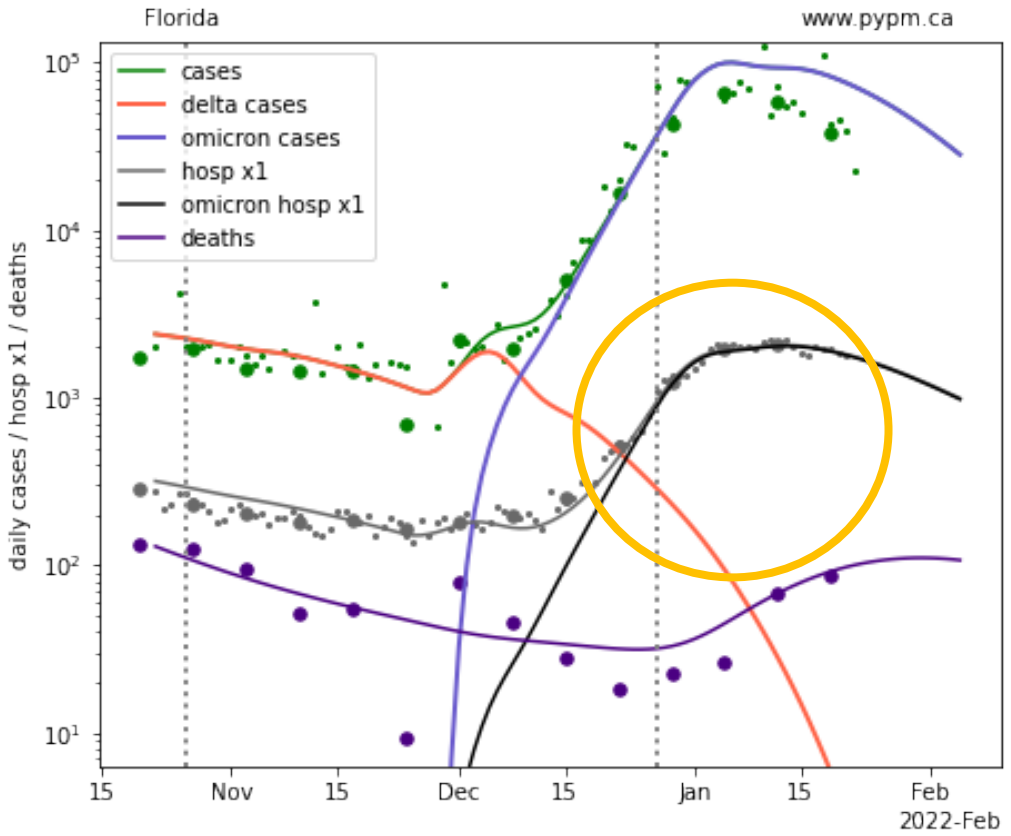
California


California
www.pypm.ca
cases
hosp x5
deaths
daily cases / hosp x5 / deaths
140000
120000
100000
80000
60000
40000
20000
0
15
Nov
15
Dec
15
Jan
15
Feb
2022-Feb

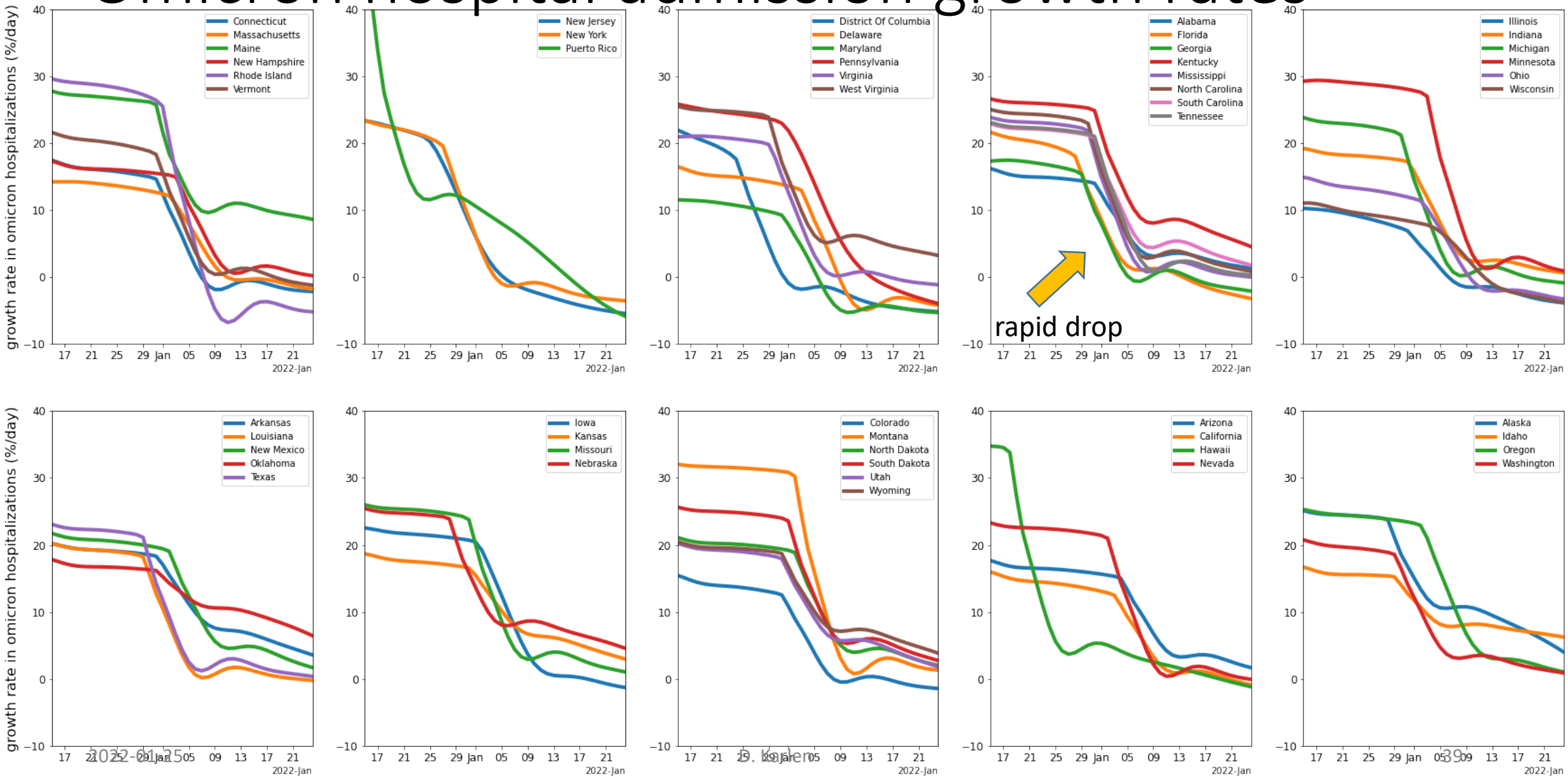

California
www.pypm.ca
cases
delta cases
omicron cases
hosp x1
omicron hosp x1
deaths
daily cases / hosp x1 / deaths
10^5
10^4
10^3
10^2
15
Nov
15
Dec
15
Jan
15
Feb
2022-Feb

Florida

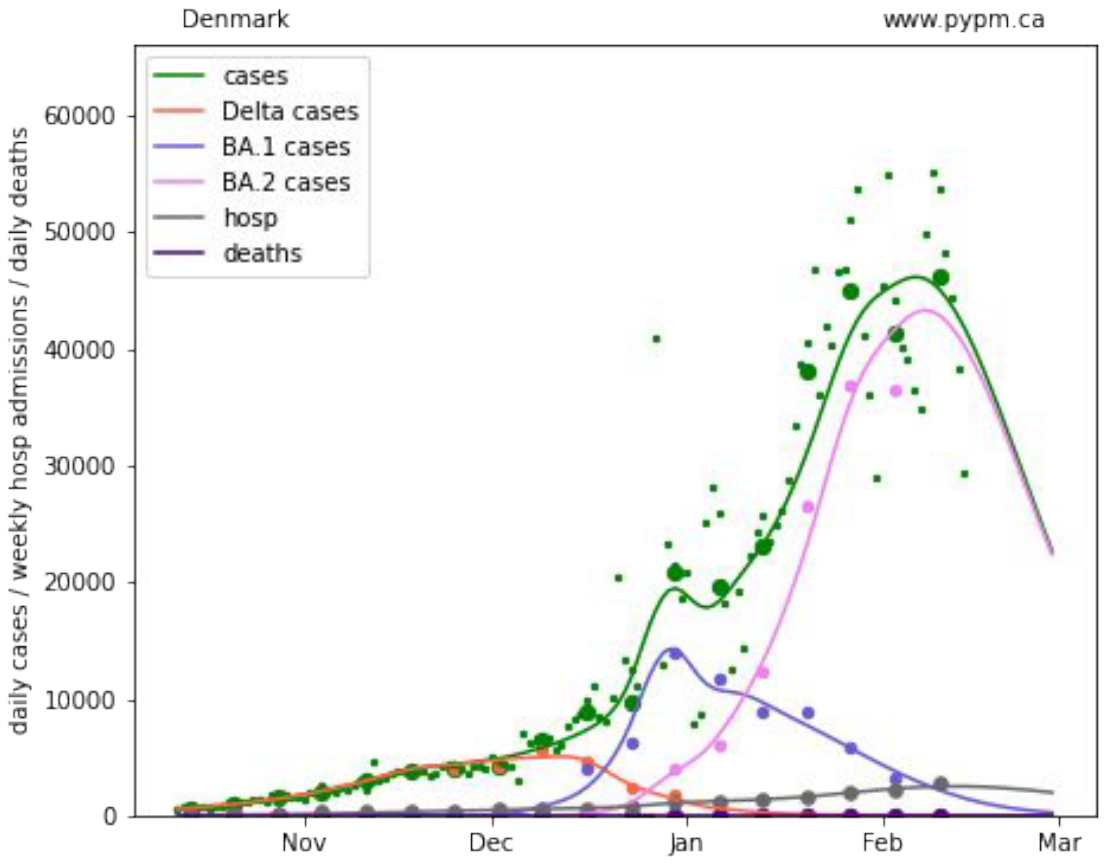

Florida
www.pypm.ca
cases
hosp x5
deaths
daily cases / hosp x5 / deaths
80000
70000
60000
50000
40000
30000
20000
10000
0
15
Nov
15
Dec
15
Jan
15
Feb
2022-Feb

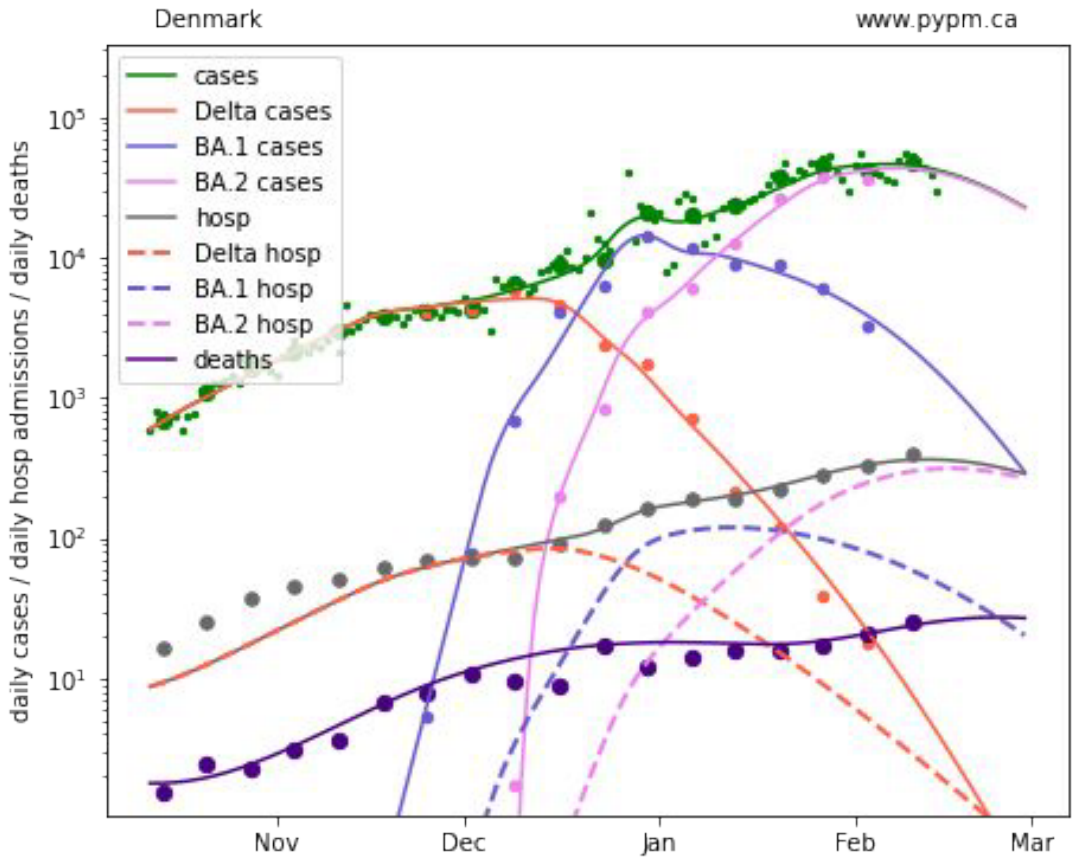

Florida
www.pypm.ca
cases
delta cases
omicron cases
hosp x1
omicron hosp x1
deaths
daily cases / hosp x1 / deaths
10^5
10^4
10^3
10^2
10^1
15
Nov
15
Dec
15
Jan
15
Feb
2022-Feb

Omicron hospital admission growth rates



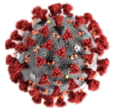
Omicron lineages and modelling Denmark hospitalizations





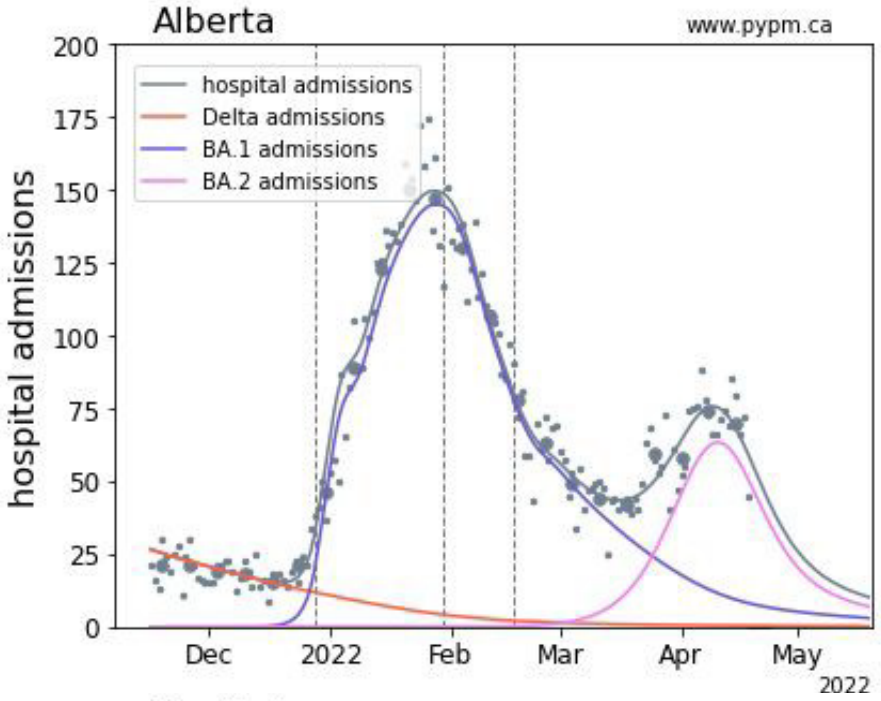
Using the lineage ratios, cases due to each lineage are inferred and fit to define a multiple-strain infection model. By fitting the model to overall hospital admission data, the relative severity of BA.2 to BA.1 infections is estimated to be about 0.7, although this is uncertain and cannot separate impact of BA.2 versus shifts over time in hospital admission rates.

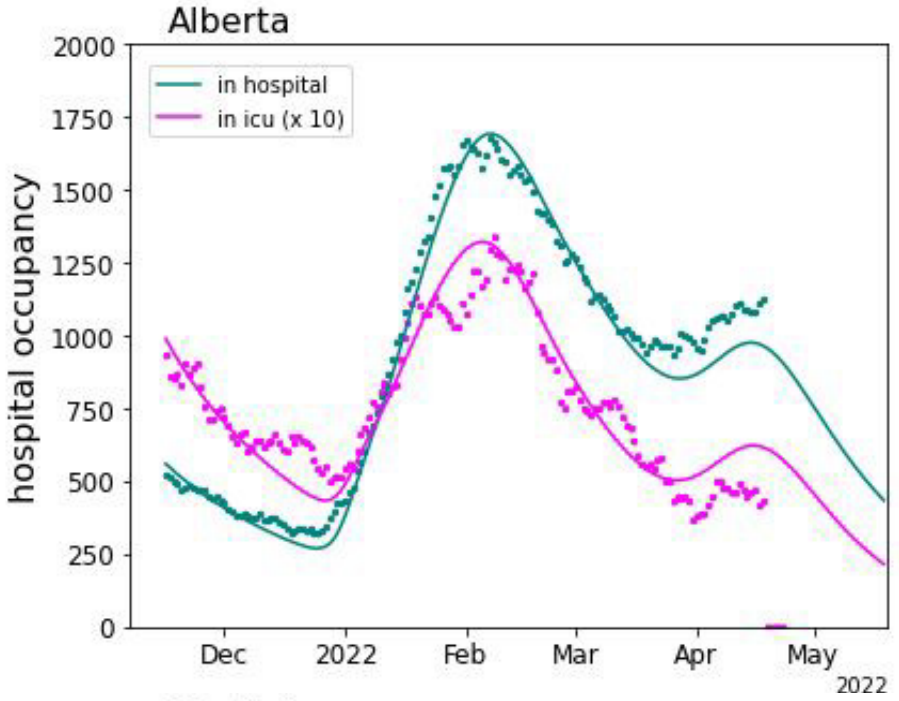
Source (D. Karlen). See www.pypm.ca. The larger dots show weekly averages. The dashed curves show hospital projections scaled to fit overall hospital admission data.

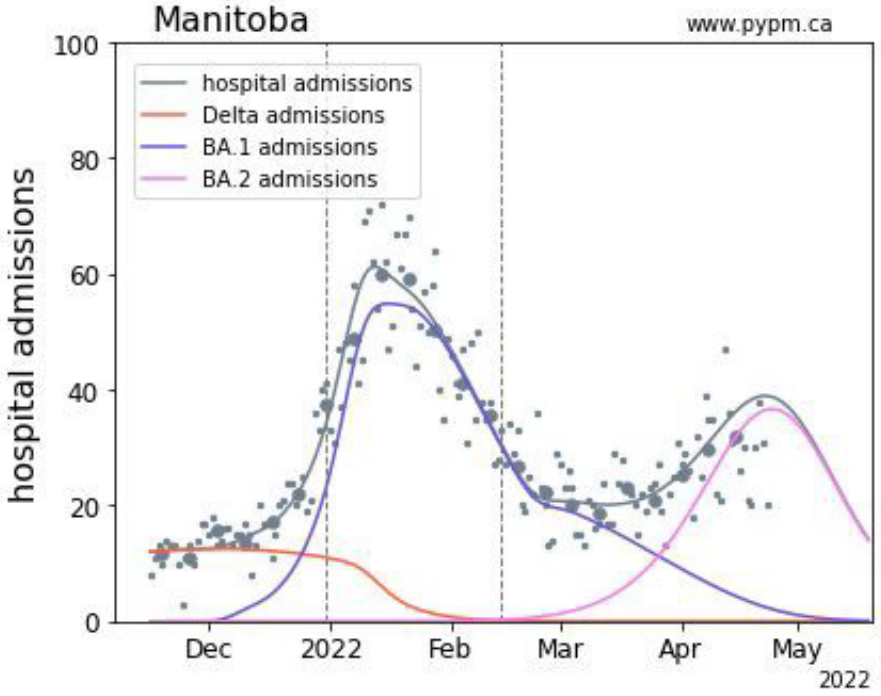


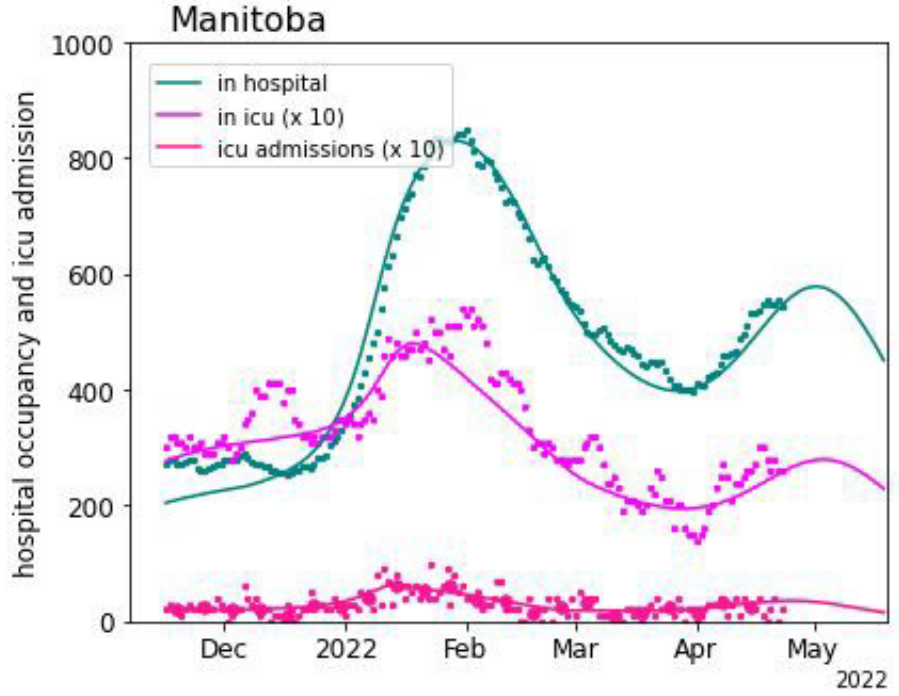
April 27 AB and MB Projections (from last report)

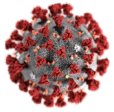
Model predicted that peak hospital admission was near its peak for both provinces.



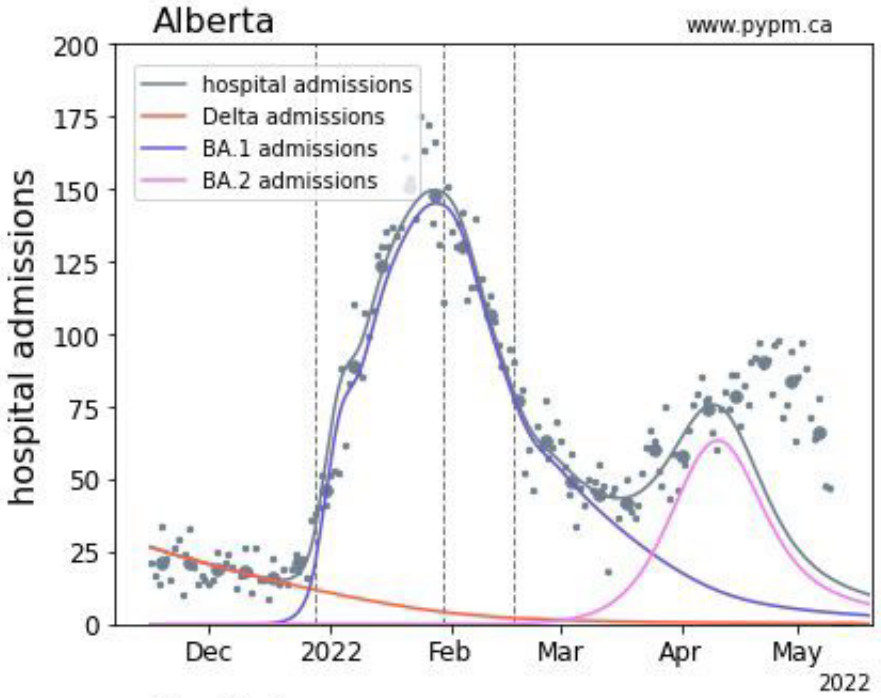


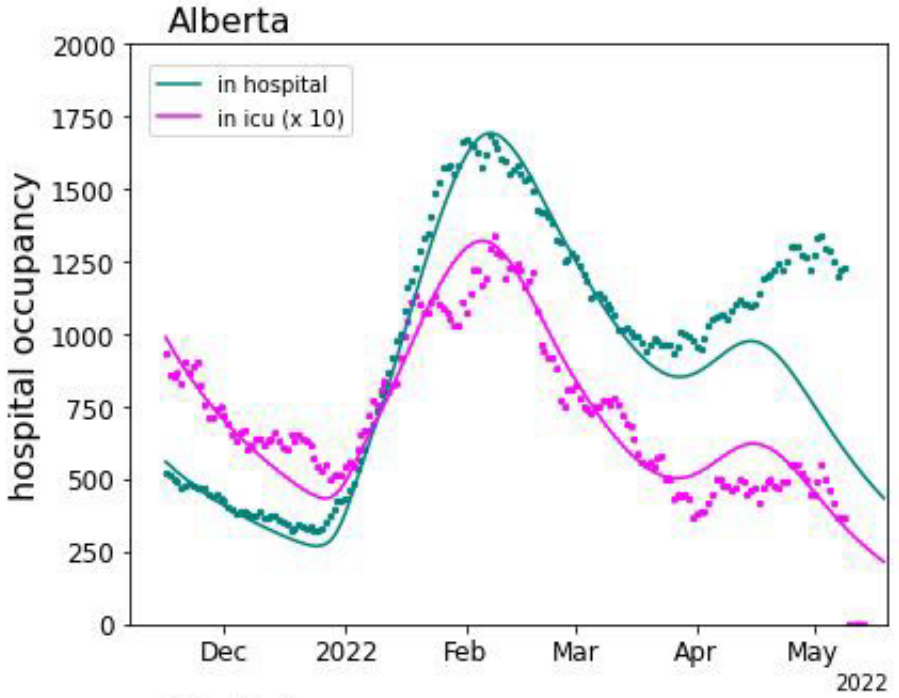






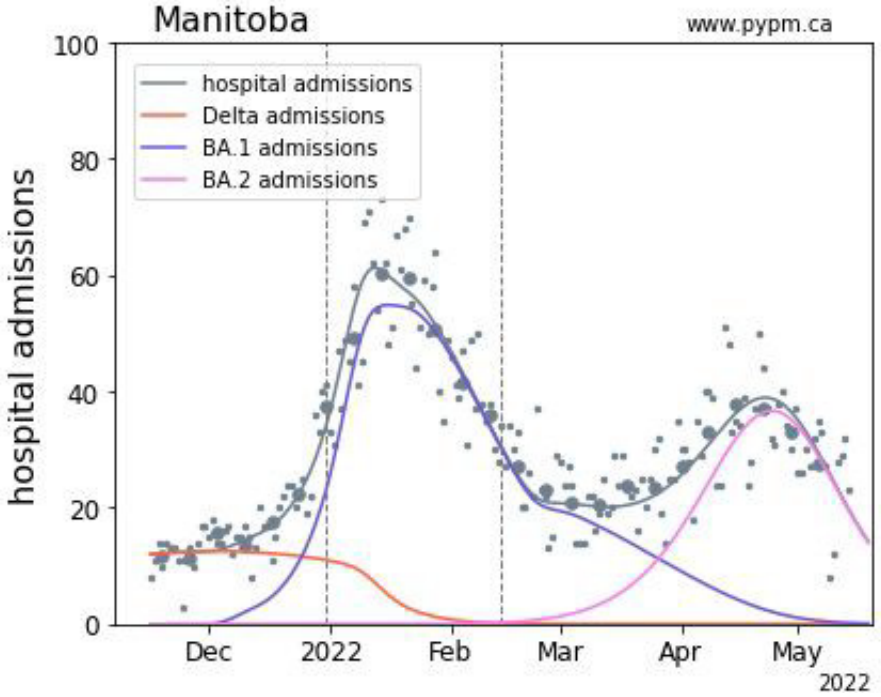
April 27 AB and MB Projections (with data update)

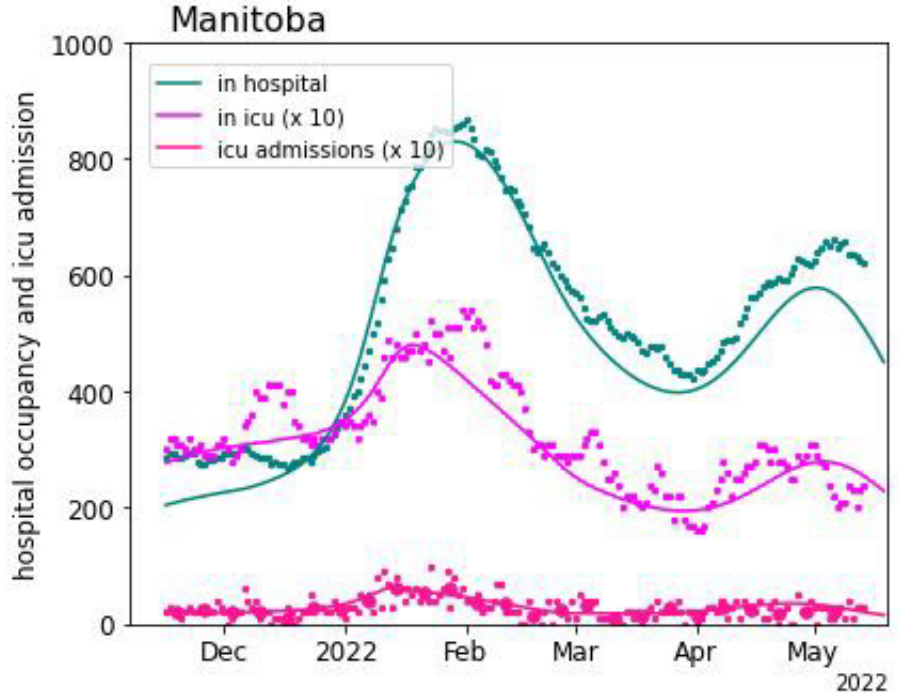




In the Alberta model, immunity grows too quickly.

- The probability for BA.2 to produce symptoms was 40% of Delta (instead of the intended value of 60%).

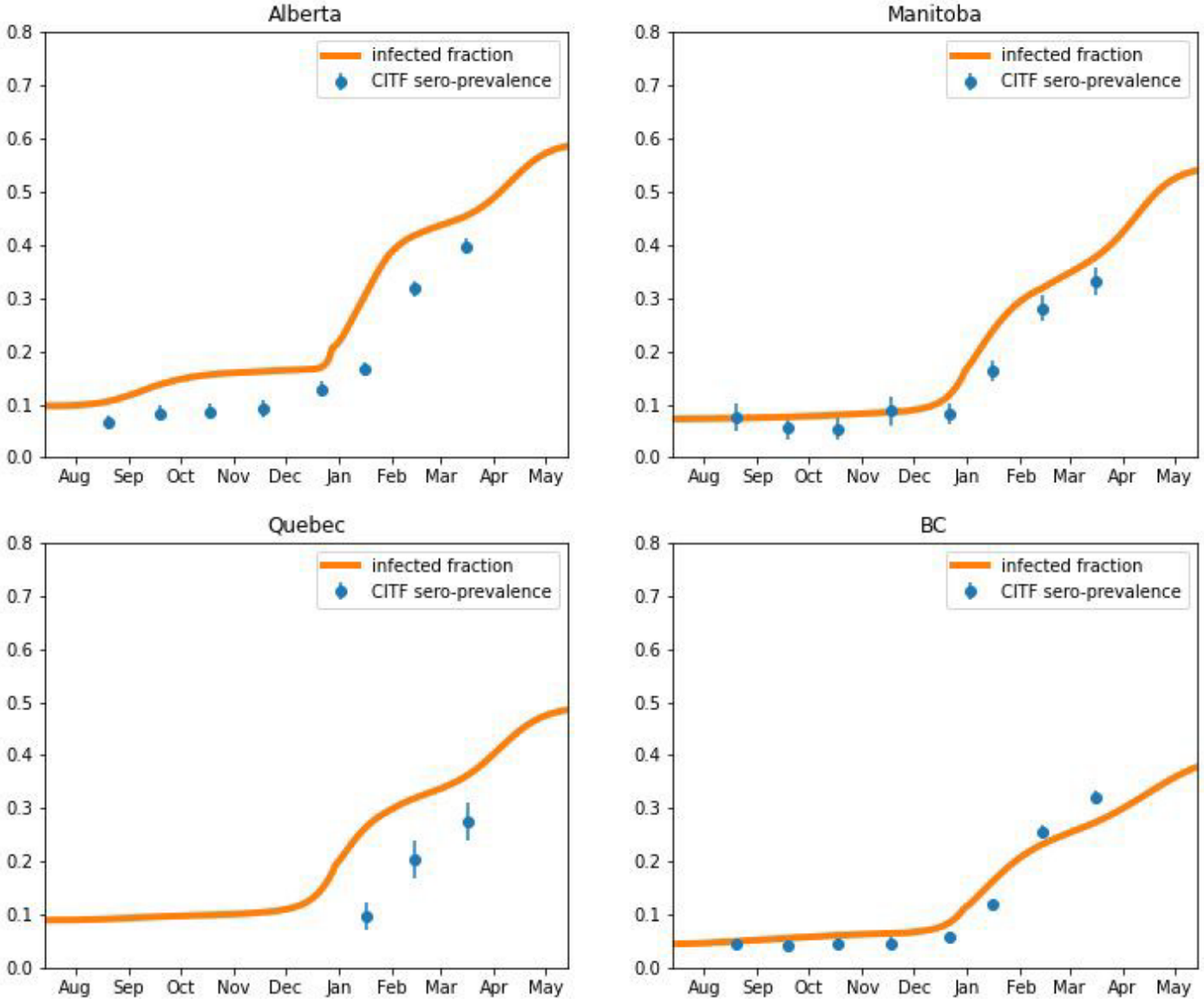




Manitoba model predicted the peak remarkably well.

- The parameter was set at 60% as intended.

Infected fraction of the population (models vs data)



A significant contribution to population immunity has come from Omicron infections.

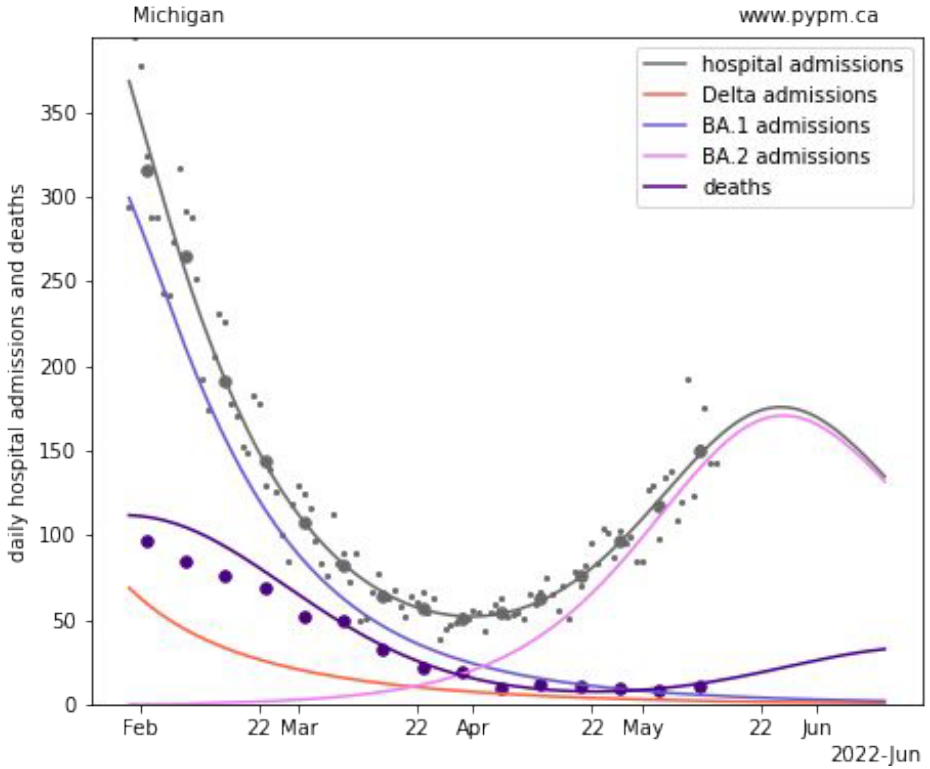
Figures on the left compare model estimates of the fraction of the population ever infected by COVID-19 (yellow curves) to data collected by the CITF representing infection rates in blood donors.

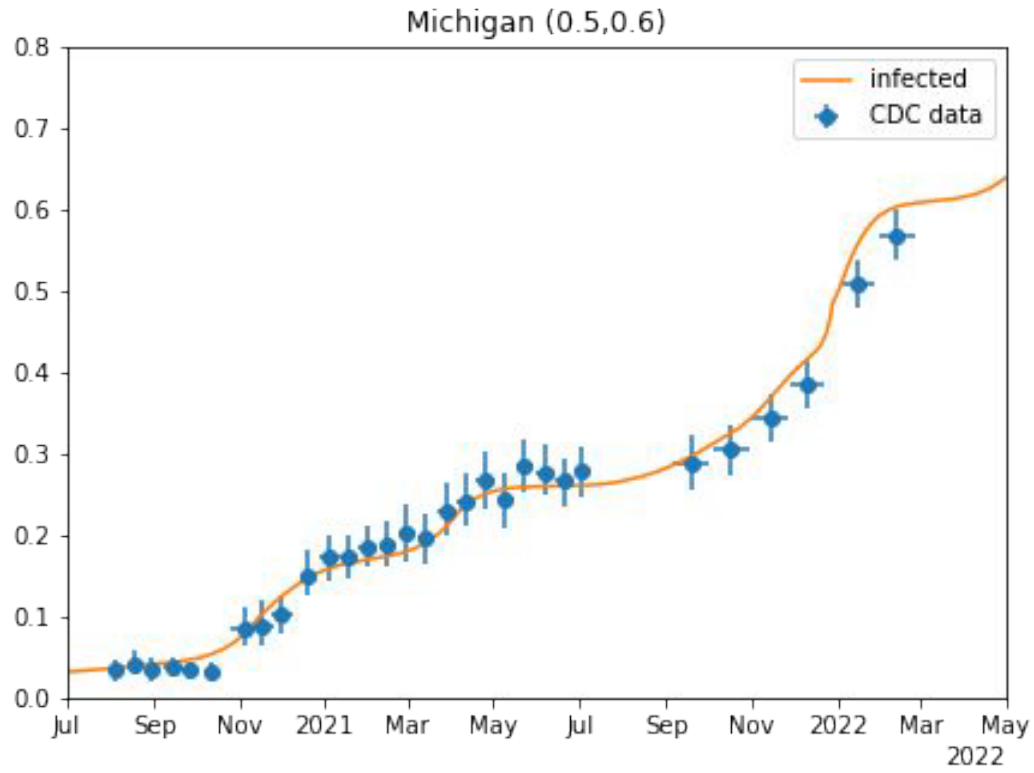
Models for Alberta and Quebec appear to have higher infected fractions than seen in data.

Source (D. Karlen) Model curves are from the updated models shown in the previous pages.

Analyses of US States

- Unlike BC, AB, MB, and QC, almost all US states have yet to reach peak hospital admissions.
- See www.pypm.ca. Right figure: fraction of population infected in model (yellow curve) compared to anti-nucleocapsid sero-prevalence data from CDC (blue points).
  - Omicron infections provide natural immunity to a large fraction of the US population.





Source (D. Karlen) As in previous reports, the model has no age structure. Two Omicron strains are included (BA.1 includes BA.1.1) with both evading 80% of natural immunity from previous strains and 80% of 2 dose vaccinations. Booster doses are assumed to provide 80% effectiveness against infection. Omicron BA.1 and BA.2 infections are assumed to produce symptoms with a probability of 60% of that for previous strains. The probability that symptoms lead to hospitalization is 30% of that for previous strains. Vertical lines show fitted dates for transmission rate changes. The larger dots show weekly averages. See: https://pypm.github.io/home/docs/studies/usa20220515/

COVID-19 ForecastHub

Home Visualization Reports Data Community About GitHub

Outcome: Hospitalizations

Location: United States

Interval: 95%

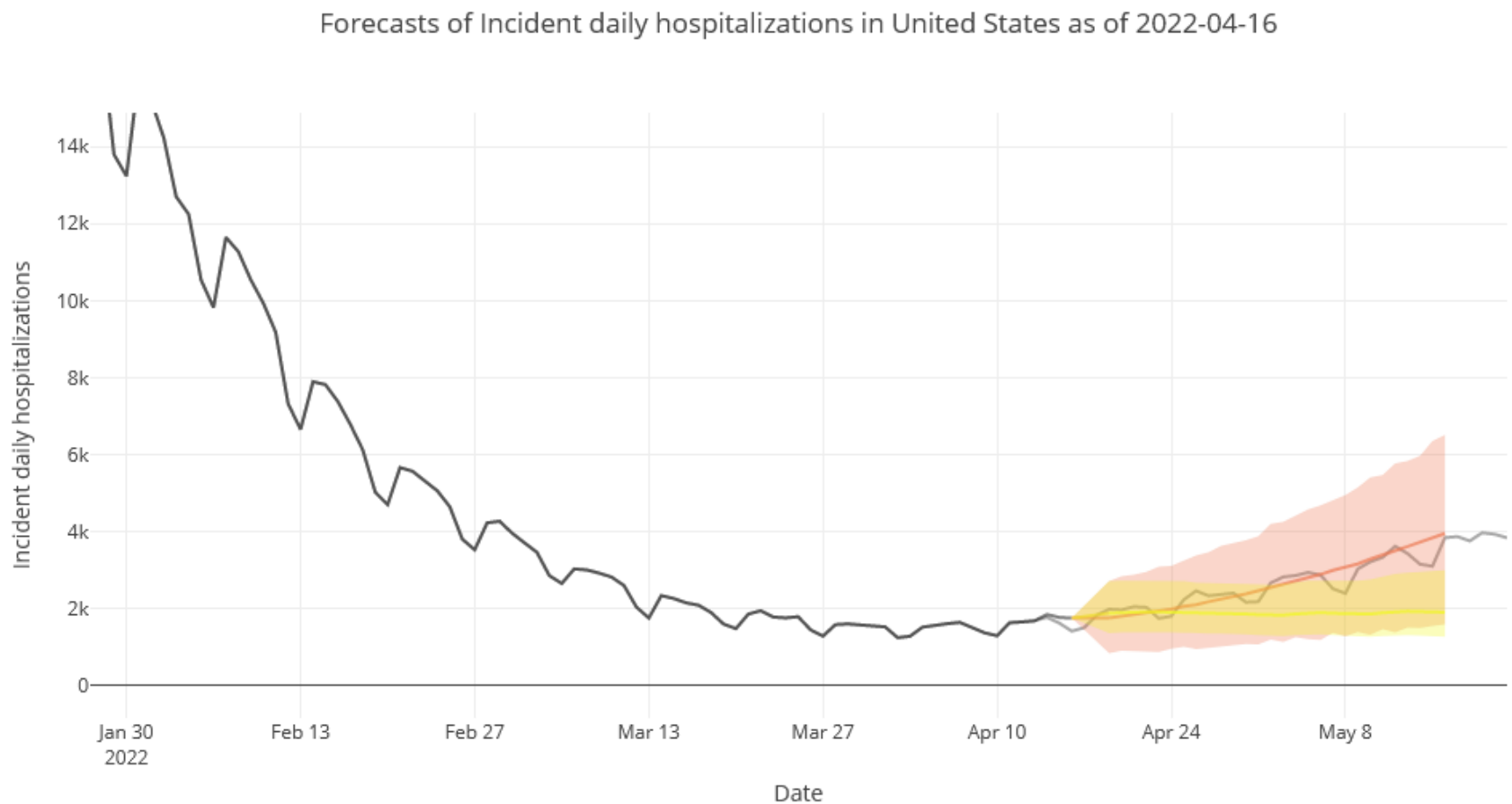
Select Truth Data:

- [x] Current (2022-05-21)
- [x] As of 2022-04-16

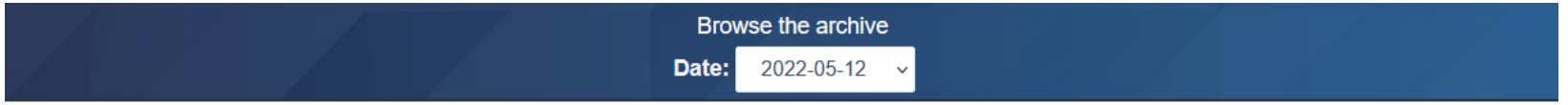
Select Models: Shuffle Colours

- [ ] JHUAPL-SLPHospEns
- [x] Karlen-pypm
- [ ] LUcompUncertLab-VAR_3streams
- [ ] MOBS-GLEAM_COVID
- [ ] MUNI-ARIMA
- [ ] prolix-euclidean
- [ ] PSI-DICE
- [ ] UMass-trends_ensemble
- [x] USC-SI_kJalpha
- [ ] UT-Osiris

Most forecasts have failed to reliably predict rapid changes in the trends of reported cases and hospitalizations. Due to this limitation, they should not be relied upon for decisions about the possibility or timing of rapid changes in trends.



Evaluation of forecasts



COVID-19 ForecastHub

- Overview
- Incident Death Forecasts
- Incident Hospitalization Forecasts
- Incident case Forecasts (state)
- Incident case Forecasts (county)

Recent accuracy | Historical accuracy | Recent coverage | Historical coverage

Show 25 entries Search:

Model	# recent forecasts	Relative WIS				Relative MAE			
		1 wk	2 wk	3 wk	4 wk	1 wk	2 wk	3 wk	4 wk
Karlen-pypm	2067	0.41	0.32	0.29	0.25	0.54	0.38	0.31	0.26
COVIDhub-trained_ensemble	2188	0.42	0.35	0.31	0.3	0.59	0.42	0.33	0.31
COVIDhub-4_week_ensemble	2200	0.47	0.4	0.36	0.27	0.66	0.45	0.38	0.28
JHUAPL-SLPHospEns	1980	0.48	0.41	0.37	0.3	0.66	0.44	0.33	0.24
CU-select	1872	0.65	0.4	0.36	0.25	0.81	0.46	0.37	0.26
JHUAPL-Bucky	2200	0.65	0.53	0.4	0.3	0.95	0.63	0.4	0.28
UT-Osiris	1772	0.46	0.44	0.5	0.52	0.67	0.52	0.48	0.43
PSI-DICE	2106	0.62	0.51	0.47	0.4	0.82	0.61	0.51	0.4
BPagano-RtDriven	2120	0.69	0.61	0.49	0.39	0.92	0.73	0.51	0.39
CMU-TimeSeries	2120	0.59	0.52	0.55	0.52	0.81	0.62	0.6	0.56
UMass-trends_ensemble	2160	0.54	0.55	0.58	0.58	0.8	0.69	0.66	0.66
USC-SI_kJalpha	2200	0.64	0.65	0.61	0.47	0.86	0.64	0.5	0.43
MUNI-ARIMA	1456	0.54	0.55	0.71	0.72	0.79	0.71	0.81	0.79
MOBS-GLEAM_COVID	2080	0.75	0.72	0.6	0.51	1.02	1.03	0.79	0.6
UVA-Ensemble	2120	0.73	0.68	0.67	0.59	0.9	0.69	0.69	0.6
JHUAPL-Gecko	2160	0.79	0.86	0.75	0.58	0.97	1	0.8	0.58

Summary