The current state of COVID-19 in Colorado

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Summary

- Hospitalizations are increasing more sharply than projections from last week.
- On the current trajectory, Colorado will probably exceed the April peak in hospitalizations (N=901) by approximately Friday, November 6th and reach ICU capacity for COVID-19 patients (N=1800) in late December. If contacts increase over the holidays, ICU capacity could be exceeded in mid-December.
- Estimated infection prevalence is higher that it has ever been in Colorado. All age groups and race-ethnic groups are impacted.
- There is evidence that transmission is increasing in older populations, leading to growth in hospitalizations in this high-risk group
- Avoiding challenging peaks in infections and hospital demand over the next two months will require a substantial and rapid increase in transmission control.
- The magnitude and timing of reductions in transmission will determine the severity of COVID-19 in Colorado in the months ahead.

Snapshot of current SARS-CoV-2 transmission in Colorado

- Effective reproductive number: 1.66 (95% confidence interval 1.24, 1.76). *Hospitalizations are increasing rapidly.*
- Estimated prevalence of infections: Approximately 638 (95% CI: 475, 689) of every 100,000, or 1 in 157 Coloradans are currently infectious. *The estimated prevalence is higher than last week.*
- Estimated number of infections to date: Approximately 9.1% (95% CI: 9.0, 9.2) of the Colorado population has been infected to date.
- Estimated current level of transmission control: 62% for the period of 10/12 to 10/20. *There is an approximate 62% reduction in total transmission-relevant contacts, inclusive of reductions due to contact tracing, self-isolation, mask wearing, and all other policy and behavioral changes compared to a situation with transmission uncontrolled, as in the very early days of the pandemic.*
- Using an extended modeling approach that includes case data, we estimate transmission control has declined for all age groups. Individuals aged 20-39 have the lowest estimated level of transmission control (Transmission control = 53%). Notably, transmission control estimates continue to decline in the oldest age group (age 65+) suggesting that people in this age group are increasingly becoming infected with the virus (Transmission control = 70%).
- There is substantial regional variation at present with increasing hospitalizations in most regions. In the Metro Area, hospitalizations are increasing rapidly in all counties.

Snapshot of the potential future trajectory of SARS-CoV-2 in Colorado

- If we remain on the current trajectory, we will probably exceed the April peak in hospitalizations by Friday, November 6th and could exceed ICU hospital capacity in December. Increases in contacts over the holidays will accelerate growth in cases and ICU hospital capacity may be exceeded earlier.
- The longer the state remains on the current trajectory, the greater the change in transmission control needed to keep hospital demand below capacity.

Introduction

We used our age-structured SEIR model and COVID-19 hospital census data to characterize the current status of the COVID-19 epidemic in Colorado and the collective impact of efforts to date to reduce the spread of the SARS-CoV-2 virus. These estimates are based on hospitalization data through 11/02/2020. We use these estimates to generate projections of the potential future course of SARS-CoV-2 in Colorado under different scenarios of transmission control measures. These include estimates of hospital needs over the next two weeks based on the current estimated trajectory, and long-term projections that consider the impact of increases in transmission control as well as increased contact rates over period from Thanksgiving to the New Year holidays.

These estimates are based on a transmission control model. We use this model to generate estimates of the effective reproductive number, to show the current trajectory of hospitalizations, to project the potential trajectory of hospitalizations under different scenarios, and to estimate the variability in transmission control by age group, using both hospitalization and case data for parameter estimation.

Model Updates This Week

Given increasing evidence of decreasing clinical severity of infections, we have updated the proportions of individuals aged 40-64 and 65+ being admitted to the ICU based on Colorado-specific data. The proportion of hospitalizations requiring ICU care has decreased in both older age groups, but has remained stable among the two younger age groups.

Current COVID-19 hospitalizations and model fit

Figure 2 shows COVID-19 hospitalizations (black bars) and the green line shows the current model fit to the data using the TC method. Table A1 provides values for model parameters for the TC approach. Our most recent estimate of transmission control, for the period 10/12 to 10/20, is 62% (95% CI = 58%, 65%). We note that due to the approximately 13-day lag between infection and hospitalization, we are currently only able to estimate social distancing and transmission control through 10/20.

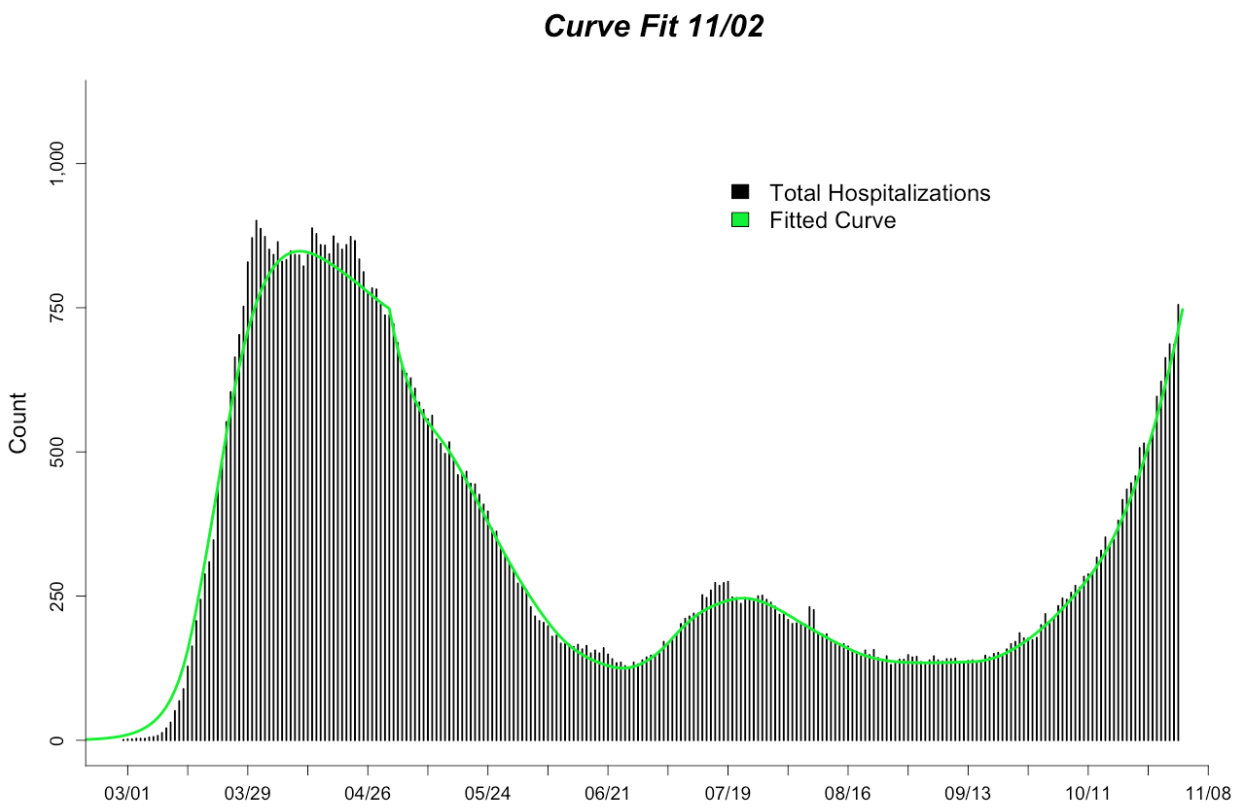


Figure 2. Current model fit (green line) to count of hospitalized COVID-19 cases (black lines) using the age-structured SEIR model. Hospitalized COVID-19 cases are from CDPHE reported COVID-19 hospitalizations and EMResource (EMR) hospital census data provided by CDPHE.

The effective reproductive number

The estimated effective reproductive number (R_E) is shown in Table 1 and Figure 3. Table 1 provides estimates we generated using two distinct but conceptually similar methods. We also provide values from RT-Live, which uses SARS-Cov-2 case. Trends in these external estimates reflect our estimates.

Table 1. Current and prior estimates of the effective reproductive number (Re) in Colorado.

	Current Estimate (11/02)	Estimate one week ago (10/26)	Estimate two weeks ago (10/19)
Estimate of Re, approach 1, TC model*	1.66 (1.24, 1.76)	1.57 (1.47, 1.70)	1.48 (1.16, 1.85)
Estimate of Re, approach 2, TC model*	1.77	1.66	1.51
Estimate from RT-Live	1.23(1.00, 1.50)	1.23 (0.96, 1.45)	1.19 (0.93, 1.41)

*Our estimates are based on hospitalization data through the date listed. Estimates from the external sites are extracted on the day listed. Because of the 13-day lag between infection and hospitalization, on average, our current estimate reflects transmission up to approximately October 20th. Approach 1 uses model output to estimate the average number of new cases generated by existing cases, accounting for the latent period and duration of infectiousness. The second method uses the model structure to estimate the dominant eigenvalue for a matrix describing population flows across the model compartments.

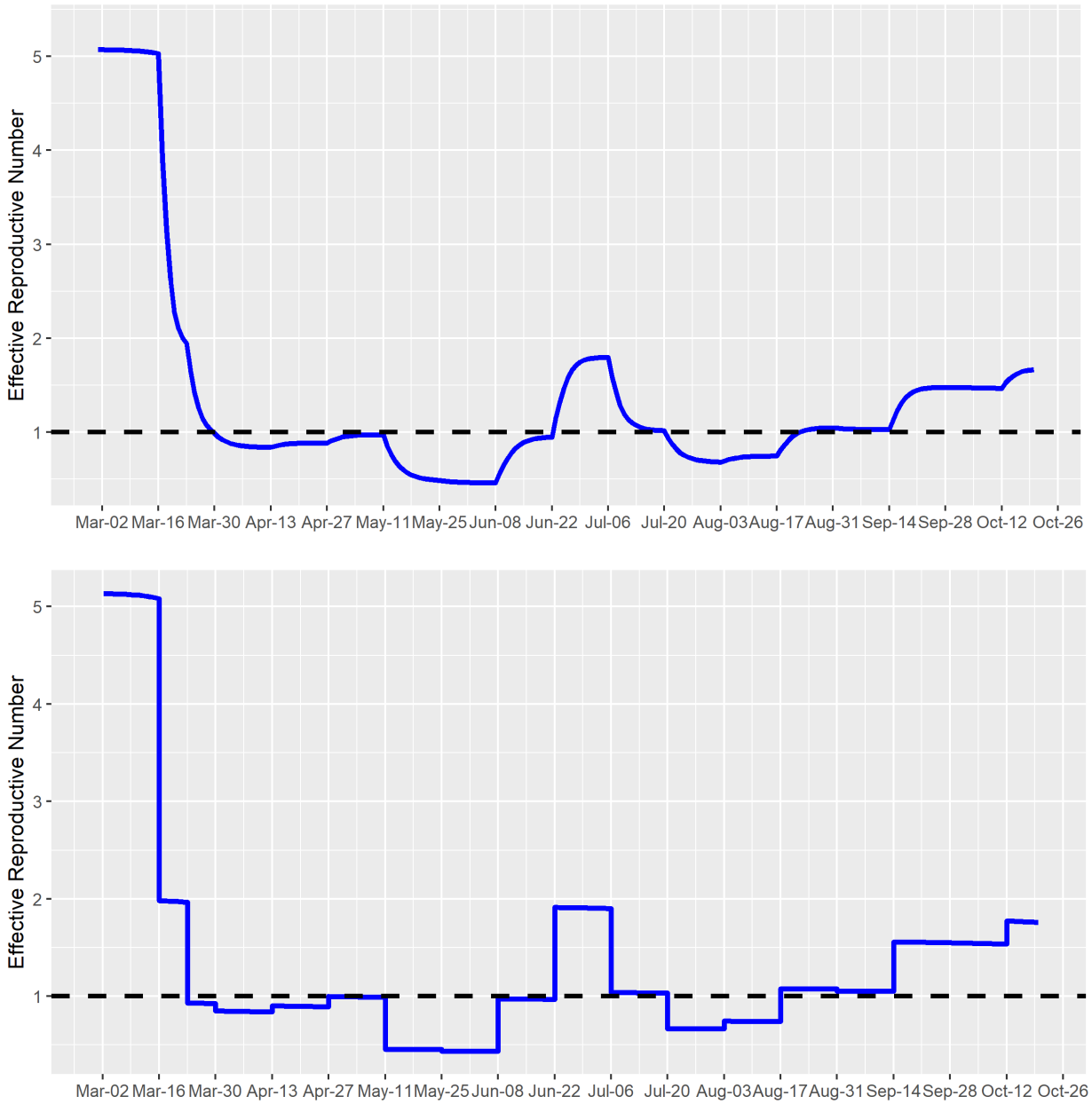


Figure 3. The effective reproductive number using approach 1 (top) and approach 2 (bottom) based on the TC model.

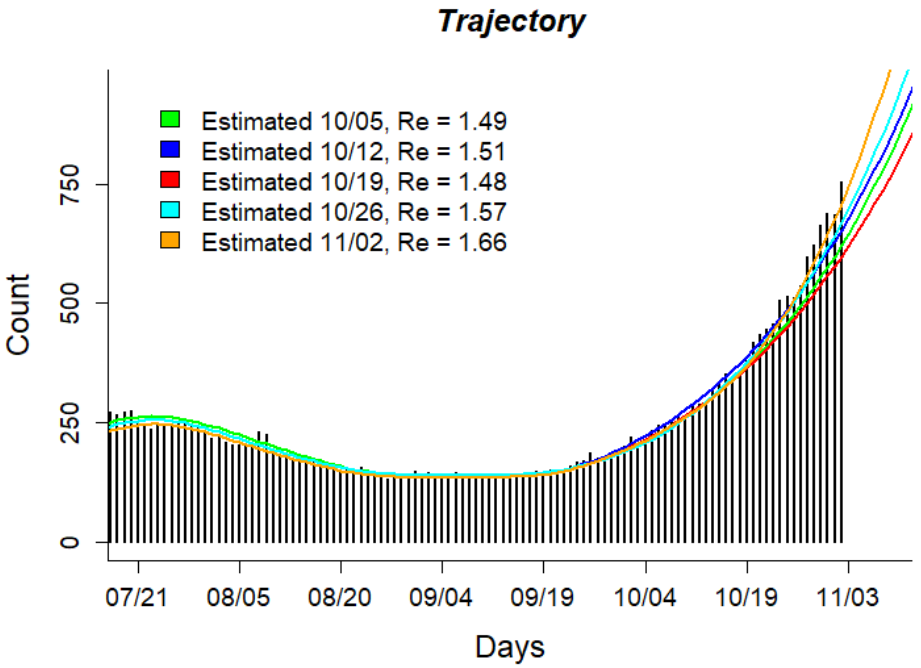


Figure 4. The projected trajectory of COVID-19 hospitalizations if Colorado remains on the current estimated trajectory (orange line), the trajectory estimated one week prior (cyan line), and the trajectory estimated two weeks prior (red line). Each trajectory is generated assuming transmission control levels remain at the estimated levels: current estimate (11/02) 62% based on the period 10/12 to 10/20, one-week prior estimate (10/26) 65% based on the period 9/28 to 10/13, two-week prior estimate (10/19) 67% based on the period 9/28 to 10/06, three-week prior estimate (10/12) 66% based on the period 9/13 to 9/29 (blue line), four-week prior estimate (10/05) 67% based on the period 9/13 to 9/22 (green line). Note that the estimation periods overlap as we re-estimate parameters each week and use the past approximately 10 days to estimate the most recent transmission control parameter.

The estimated cumulative and current number of infections in the population

We use the TC model to estimate the cumulative number of infections to date and the approximate number of infectious individuals in the population. Given the characteristics of SARS-CoV-2 and of COVID-19, many infections are not detected by surveillance systems – the estimates provided here are intended to provide an approximation of the total number of infections, as well as the proportion detected by Colorado's surveillance system. These estimates are sensitive to model assumptions, including assumptions about the probability an infected individual will be symptomatic and require hospital care, as well as estimates about length of hospital stay, which vary over time, all variables of which we assume varies by age.

We estimate that approximately 533,000 (95% CI: 529,000, 536,000) people in Colorado, or 9.1% (95% CI: 9.0, 9.2) of the population, have been infected to date.

We estimate that there are approximately 37,000 (95%CI: 28,000, 40,000) infectious individuals in Colorado at present: approximately 638 (95% CI: 475, 689) of every 100,000 Coloradoans or 1 in every 157 people (95% CI: 145, 210). Figure 5 illustrates the relationship between COVID-19 hospitalizations

and the estimated number of infectious individuals at any given point in time. The number of infectious individuals is approaching the March/April peak. This implies that individuals are more likely to encounter infectious individuals in the population than they were this spring and summer.

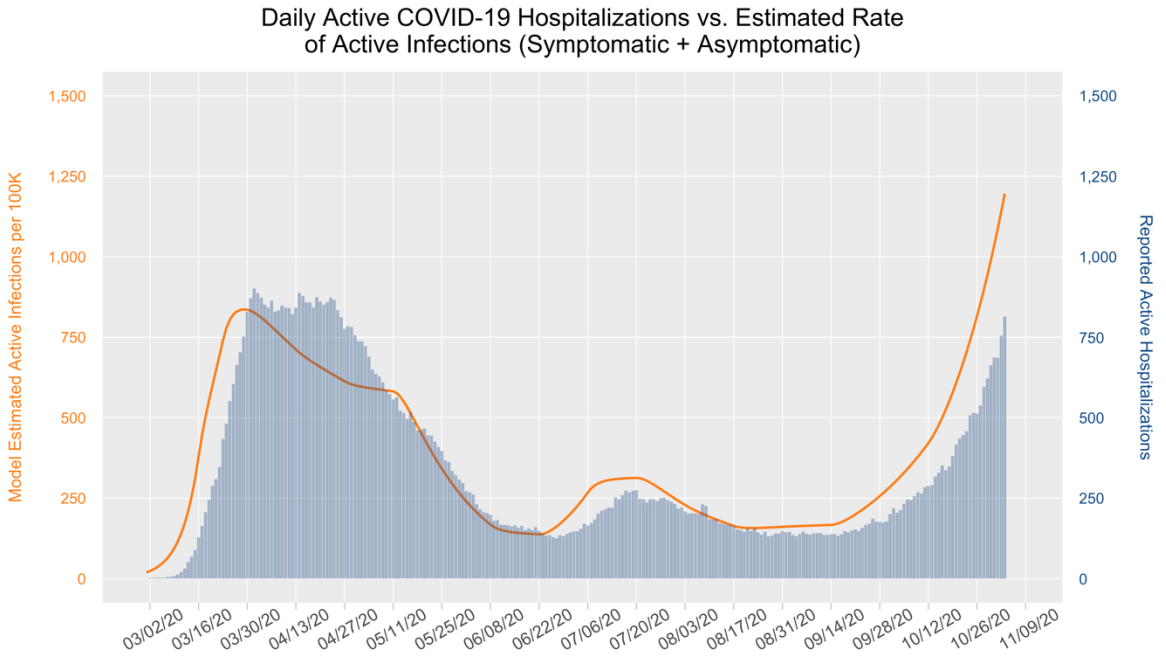


Figure 5. Estimated daily number of people (per 100,000 population) who are infectious and infected with SARS-CoV-2 (point prevalence), as shown on the orange line, and the number of actual COVID-19 hospitalizations (blue bars). The number of infectious individuals is inferred using the model and based on hospitalizations.

Comparing observed to model-estimated infections, we estimate that approximately 44% of infections in the past two weeks were detected, including both asymptomatic and symptomatic infections.

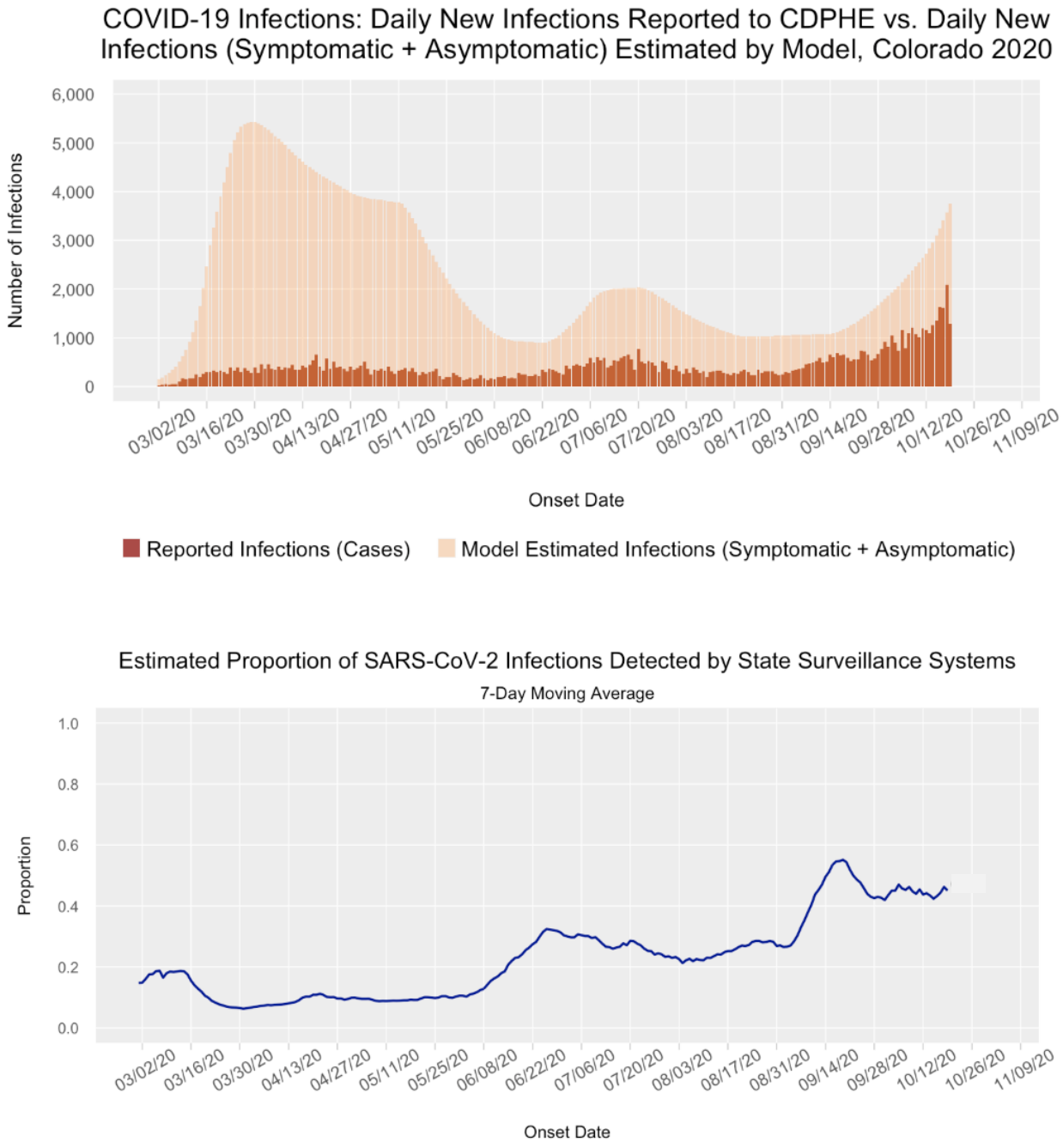


Figure 6. Estimated daily number of new (incident) SARS-CoV-2 infections based on the SEIR model (light orange graph) and reported cases (dark orange graph) over time shown in the top panel. Lower panel shows the 7-day moving average of the estimated proportion of SARS-COV2 infections that are being captured by Colorado state surveillance systems, over time. The proportion detected is estimated by dividing the total number of new cases captured by state surveillance systems by the model-estimated number of new infections each day. The number of cases captured by state surveillance systems is the number of cases reported by CDPHE, using the onset date of symptoms (if onset date is not available, onset date is imputed by CDPHE using a proxy distribution of recent onset dates). Data are shown through 10/20 to account for typical lags between symptom onset and case report.

The distribution of reported infections and hospitalizations by age, race and ethnicity

Reported SARS-CoV-2 Cases by age group. Figure 7 shows the 7-day moving average of reported new SARS-CoV-2 infections by age group. Recent reports of new cases are highest for those aged 20 - 39. The average proportion of COVID-19 cases in people under age 40 over the last two weeks is approximately 56%.

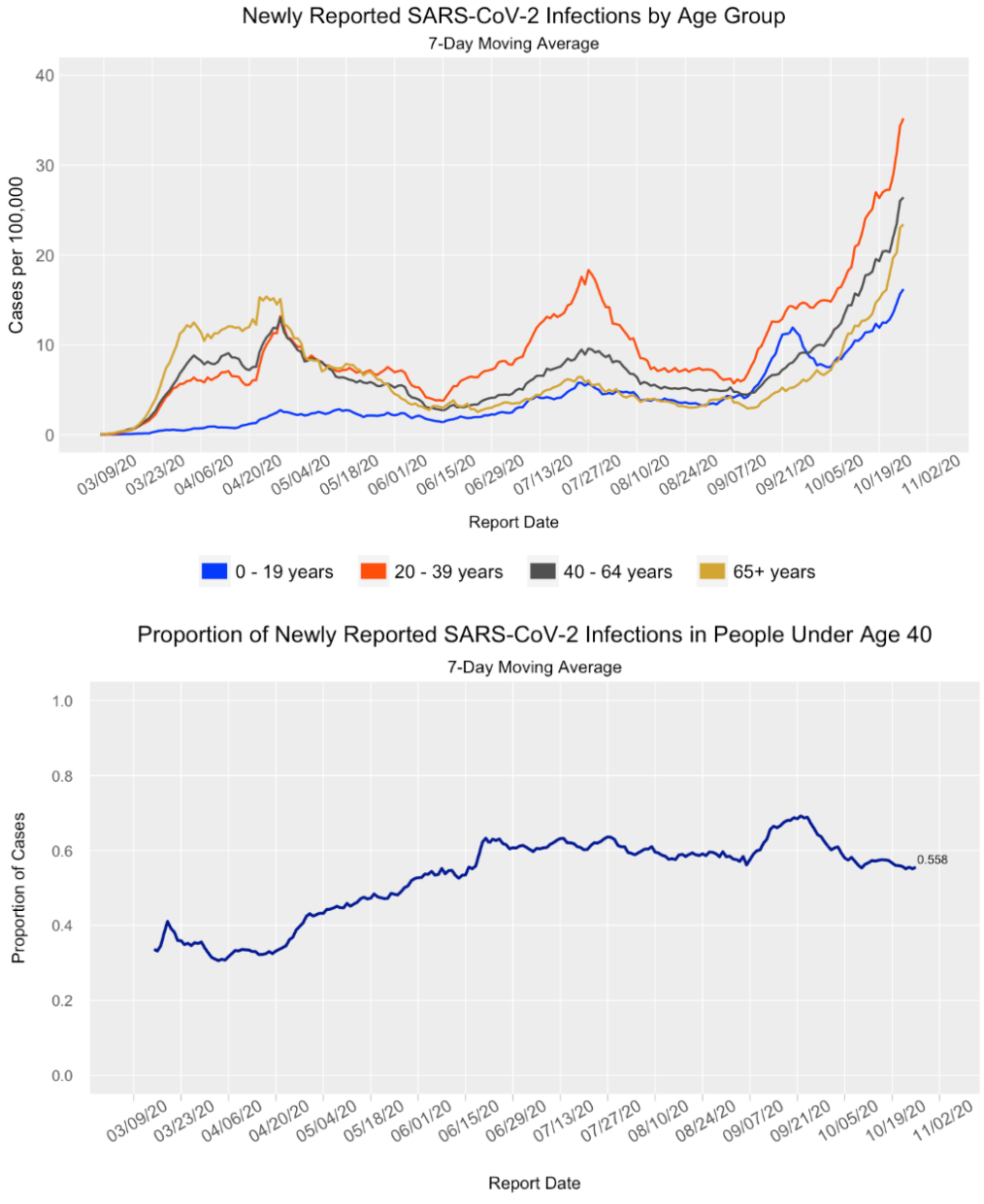


Figure 7. Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by age group (top) and the proportion of all cases among individuals under 40 (bottom). Reported cases are based on CDPHE data and shown by report date. Incident cases per 100,000 were obtained by standardizing weekly reported age-specific case and hospitalization counts to the Colorado population distribution by age, gathered from the Colorado Census 2020 estimates. Data are shown through 10/26/2020, to account for typical lags between case report and data updates.

COVID-19 hospitalizations by age group. Figure 8 shows the number of individuals hospitalized with COVID-19 by age group from March through the present, based on COPHS hospital census records. Currently, individuals age 65+ account for the greatest COVID-19 hospital use. People under 40 account for approximately 13% of COVID-19 hospital use, on average, over the last two weeks.

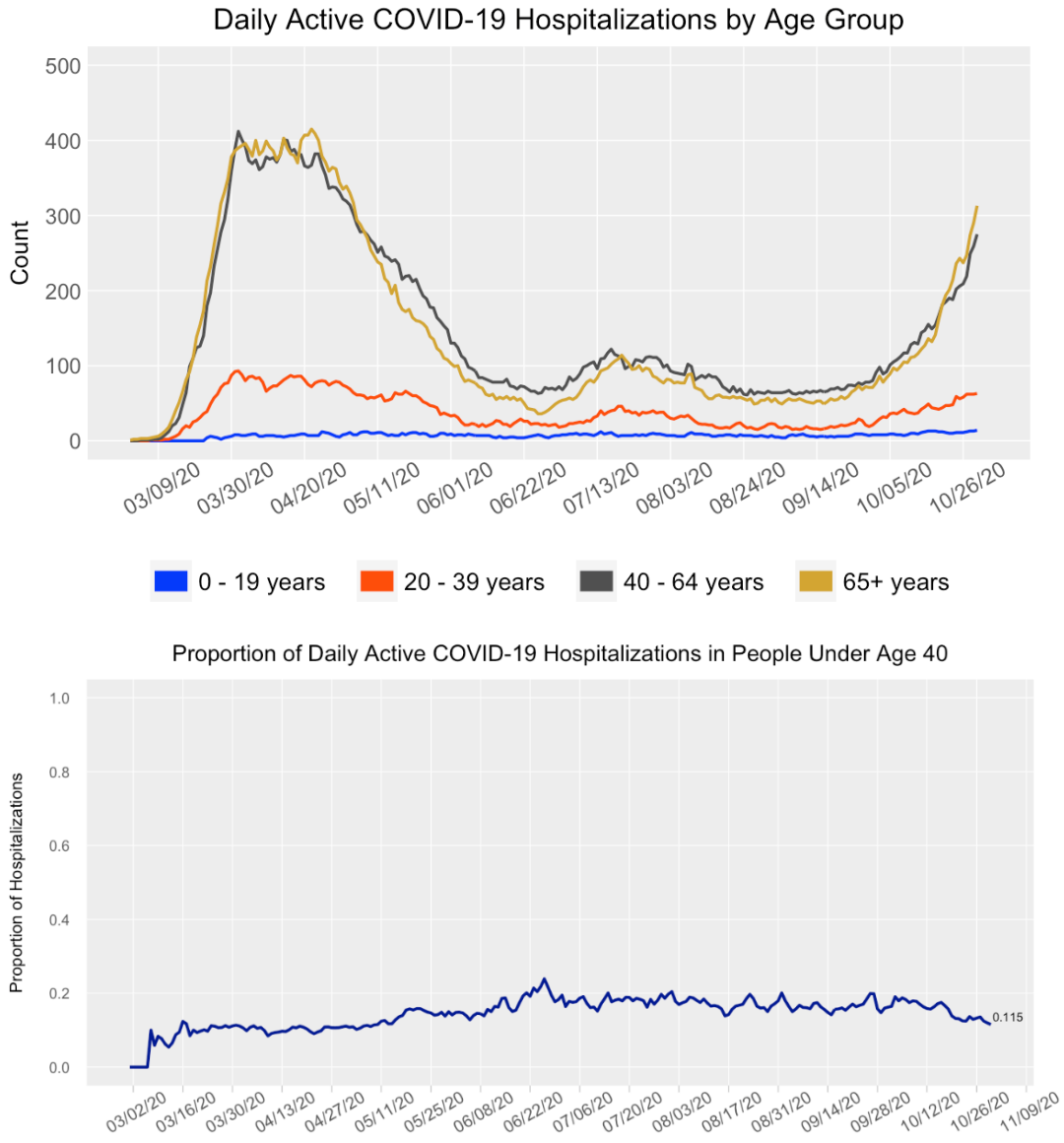


Figure 8. The number of individuals hospitalized with COVID-19 by age group from March through the present (top) and the proportion of COVID-19 hospital beds occupied by individuals under age 40. Data based on COvid Patient Hospitalization Surveillance (COPHS). Data shown through 10/28.

COVID-19 reported cases by race/ethnicity. Figure 9 shows the number of reported cases by race/ethnicity from March through the present. Hispanic populations continue to be disproportionately impacted.

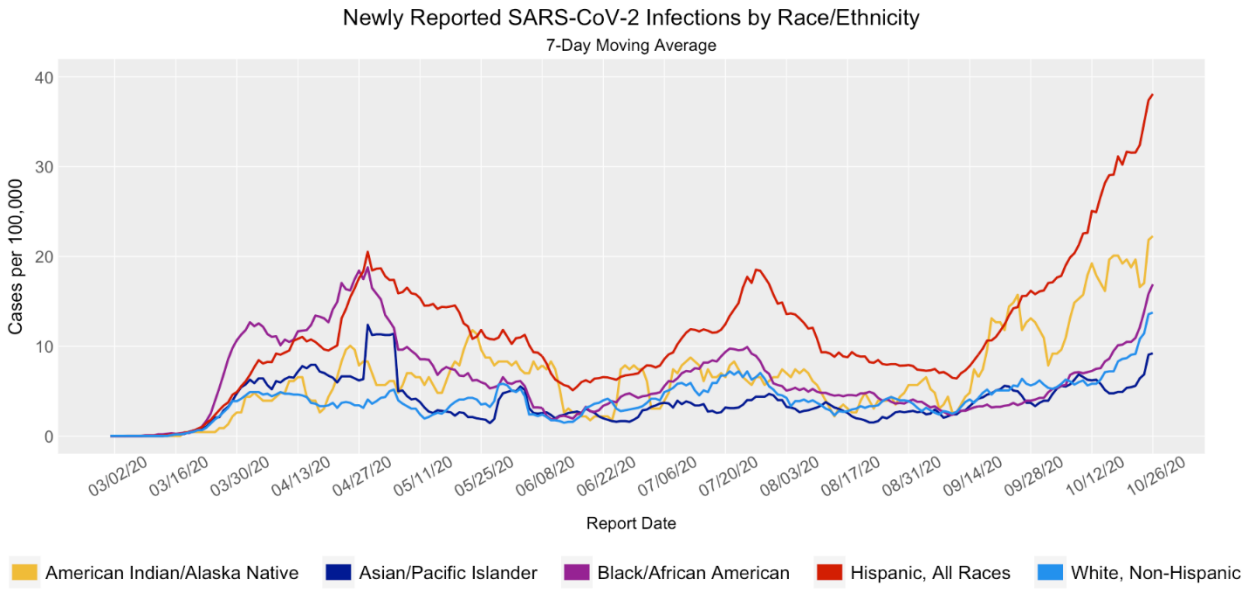


Figure 9. Distribution of 7-day moving average of newly reported SARS-CoV-2 infections by race and ethnicity in Colorado. Reported cases are based on CDPHE data and shown by report date. Cases and hospitalizations per 100,000 were obtained by standardizing weekly reported race-specific case and hospitalization counts to the race/ethnicity distribution of the state of Colorado gathered from the CDPHE COVID-19 Case Summary Dashboard. These standardized estimates combine Asian and Native Hawaiian/Pacific Islander races and exclude Other/Unknown races (which account for 32% of observations over the last two weeks).

Using age-specific case data to estimate transmission control behaviors by age

Due to the variation in behavior by age and the increase in cases seen among younger age groups, we estimate how transmission control varies by age group. We use CEDRS case data presented in Figure 7 to fit age-group specific levels of transmission control. We make the following assumptions about detection rate: We take the probability of detection from the overall model (calculated by comparing daily model estimated infections to reported infections (Figure 6)) as a time series (daily time-step) and fit observed CEDRS case data to age-specific estimated infections over time. To account for age-specific differences in detection rate, we fit parameters for age-differences in detection rate to hospitalization data and then refit the TC parameters to case data. Transmission control levels continue to decrease among all age groups. Individuals aged 20-39 have the highest contact rates currently (TC= 53%). In all other individuals, cases have increased recently, leading to a decreased estimate of transmission control (TC = 70%, 62%, and 70% for individuals under 20, 40-64, and 65+ respectively).

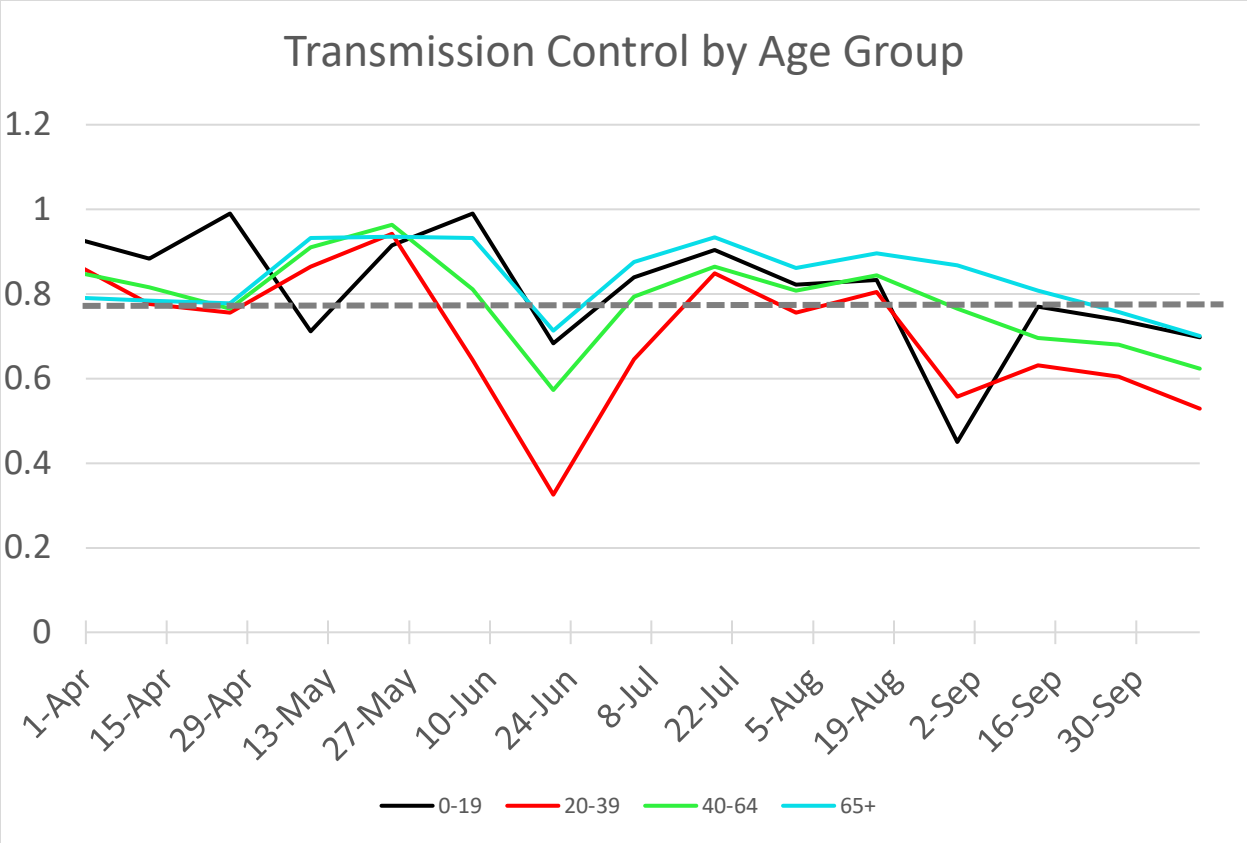


Figure 10. Estimates of transmission control by age plotted over time. Transmission control values are plotted at the time period for which they begin, as the last period for which transmission control is estimated is 10/12 – 10/20, the point on the graph is plotted at 10/12. Grey dashed line indicates threshold value of transmission control = 78%.

Near-term forecast

We generated estimated hospitalizations and ICU need over the next two weeks assuming Colorado remains on the current trajectory and accounting for uncertainty in our current estimated trajectory (Figure 11, bottom). The mean estimate crosses 901 hospitalizations (the prior peak) on ~November 6th; however there is a chance we could cross 901 hospitalizations as early as November 5th. These estimates are based on 10,000 simulated runs, with 1,000 of those runs randomly selected for visualization.

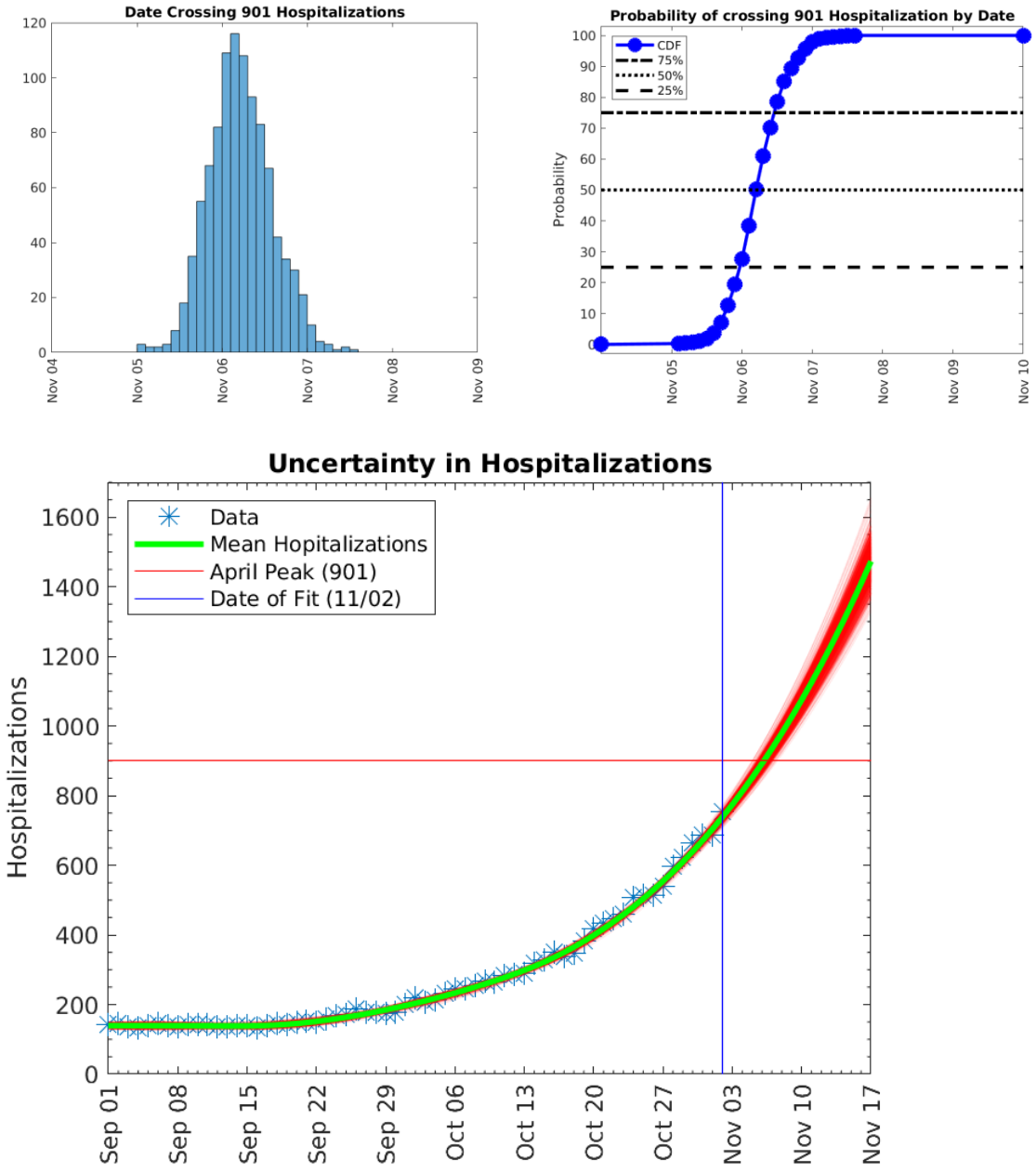


Figure 11. Distribution of likely timing for crossing previous hospitalization peak (901 hospitalizations) (top) and estimated daily count of total hospital demand (bottom) if we remain on the current trajectory (solid line, 62% for the period 10/12 – 10/20). Additional lines show the range of uncertainty in our current trajectory.

Scenario-based projections

Projections were generated to evaluate future case numbers, and hospital and ICU need under an array of hypothetical scenarios.

- The first set of scenarios shows the potential impact of theoretical changes to the current trajectory
- The second set of scenarios considers the potential impact of increased population mixing and more social contacts over the holidays

Projection set 1. Changes to the current trajectory.

In these scenarios, transmission control values are altered from the current trajectory and increased or decreased on 10/30 (Figure 12 and Table 2).

Projections show that at the current level of infectious contact rates we could see substantial growth in cases in the months ahead, and ICU capacity would be expected to be exceeded in January.

Table 2. Comparison of the projected date that ICU capacity is reached, the date that ICU demand peaks, the estimated number of ICU beds needed at the peak, and the cumulative COVID-19 deaths at different levels of transmission control.

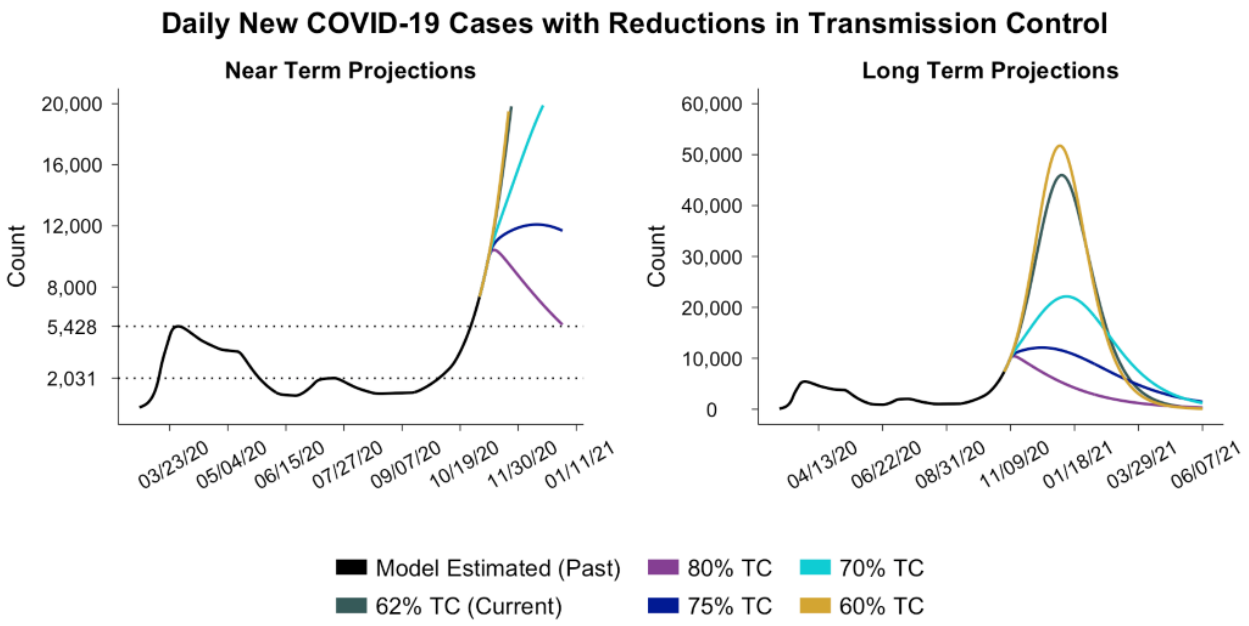
	Date ICU Capacity Reached*	Date of ICU Peak	ICU Need at Peak**	Cumulative cases through 12/31/2020**	Cumulative deaths through 12/31/2020**
Projection set 1: Changes to the current trajectory ¶					
Current trajectory (10/12 – 10/20, TC = 62%)	12/29/2020	1/11/2021	2,000	2,770,000	8,500
TC = 80%	N/A	11/23/2020	430	1,160,000	4,300
TC = 75%	N/A	12/22/2020	540	1,430,000	5,000
TC = 70%	N/A	1/17/2021	980	1,840,000	5,900
TC = 60%	12/22/2020	1/9/2021	2,250	3,020,000	9,600
Projection set 2. Increased contacts over the holidays Holiday scenarios (10% decrease over holidays)**					
Baseline TC = 62% (current)	12/18/2020	1/8/2021	2,700	3,360,000	11,000
Baseline TC = 80%	N/A	1/8/2021	600	1,440,000	4,900
Projection set 3. Increased contacts over the holidays Holiday scenarios (20% decrease over holidays)**					
Baseline TC = 62% (current)	12/13/2020	1/5/2021	3,300	3,940,000	14,300
Baseline TC = 80%	N/A	1/11/2021	1,250	1,910,000	5,800

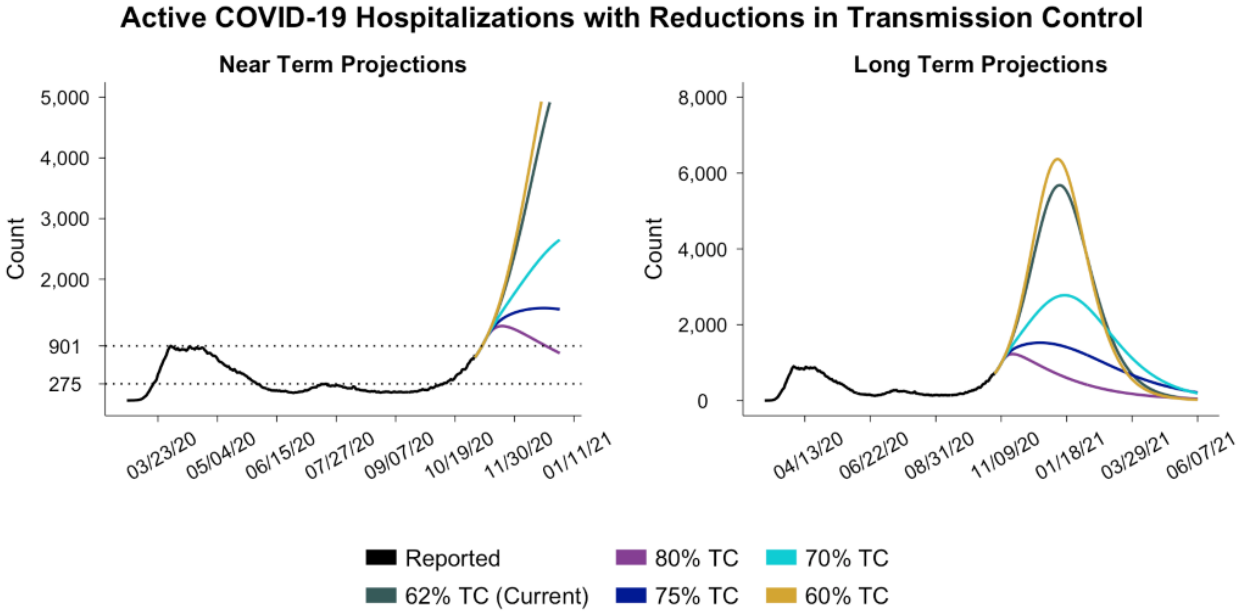
*ICU capacity for COVID-19 patients is estimated to be 1800 in Colorado, a figure provided by CDPHE.

**Estimates are rounded to three or two significant figures.

¶ Intervention are modeled assuming social transmission control levels remain at the current estimated level until 11/06, at which point it changes to the indicated value. These scenarios do not account for any additional changes in contacts over the holidays.

** Holiday scenarios assume transmission control values remain at current level until 11/06 and then switch to indicated value at 11/06. Transmission control values remain at indicated value until 11/20, at which point they decrease by a relative 10% reduction. The decreased value remains until January 3rd, when the TC level switches back to the indicated baseline TC value.





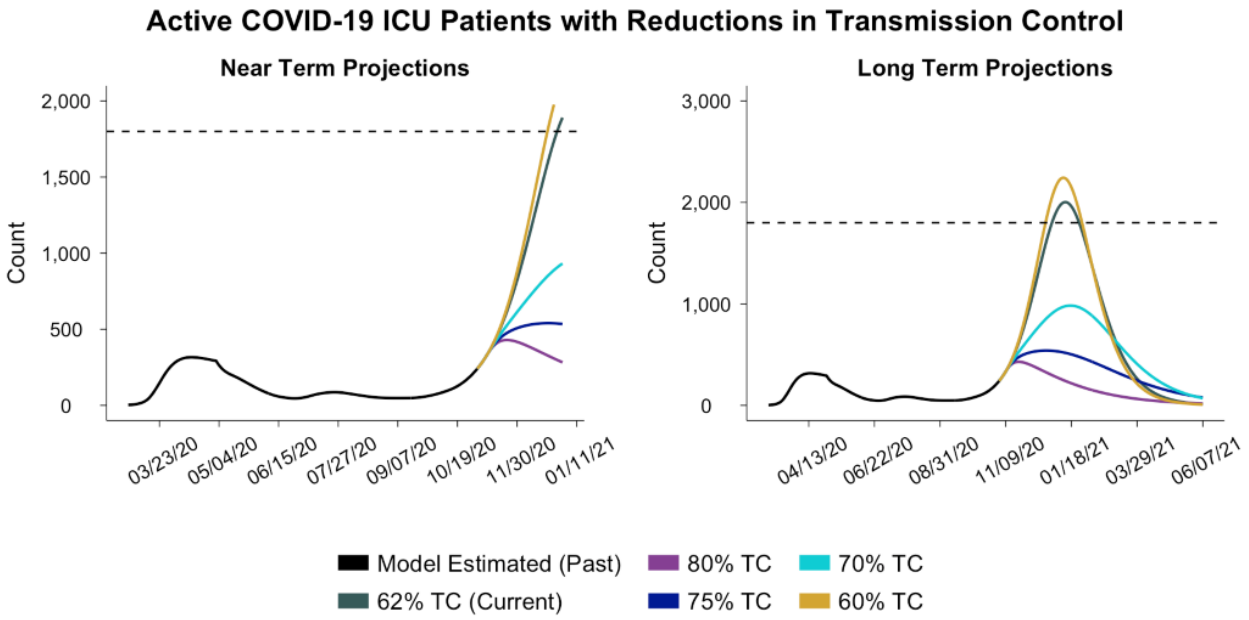


Figure 12. Projected daily count of new infections (top), active hospitalizations (middle) and active ICU patients (bottom) varying levels of transmission control, assuming transmission control remains at current levels (62%), or switches to 80, 75, 70, or 60% on 11/06. Dotted lines on the new infections plot indicate the number of new infections estimated during the April and July peaks. Dotted lines on the ICU need plot indicate estimate ICU capacity = 1,800.

Projection set 2. Decreases in transmission control levels during the holiday season

Given the recent rise in cases around the Independence Day (TC = 60%) and Labor Day holidays, we generated preliminary scenarios to evaluate the potential impact of theoretical increased social contacts over winter holidays. These scenarios assume contact rates increase starting the Friday before Thanksgiving, 11/20/2020, and that the increment in contact lasts until 1/03/2021. We do not know what the true increase in infectious contacts will be over the holiday season – we modeled 10% and 20% relative decreases in transmission control levels as preliminary scenarios. We generated projections assuming 1) we remain at our current transmission control level (62%) until 11/20/2020, and 2) assuming we switch to 80% transmission control on 11/06/2020 and remain there until 11/20/2020. This allows us to examine the extent to which the level of infections entering the holiday season impacts the severity of any increase in cases over the holidays.

As shown in Figure 13 and Table 2, a holiday-related increase in contacts has the potential to lead to an increase in infections and hospital demand. If we remain on the current estimated trajectory, and experience an increase in contacts, ICU capacity could be exceeded in early December. This increase will happen more rapidly, and the peak will be higher if we enter the holidays at a higher level of infection. Controlling infections in October and November can reduce the severity of a holiday “bump.”

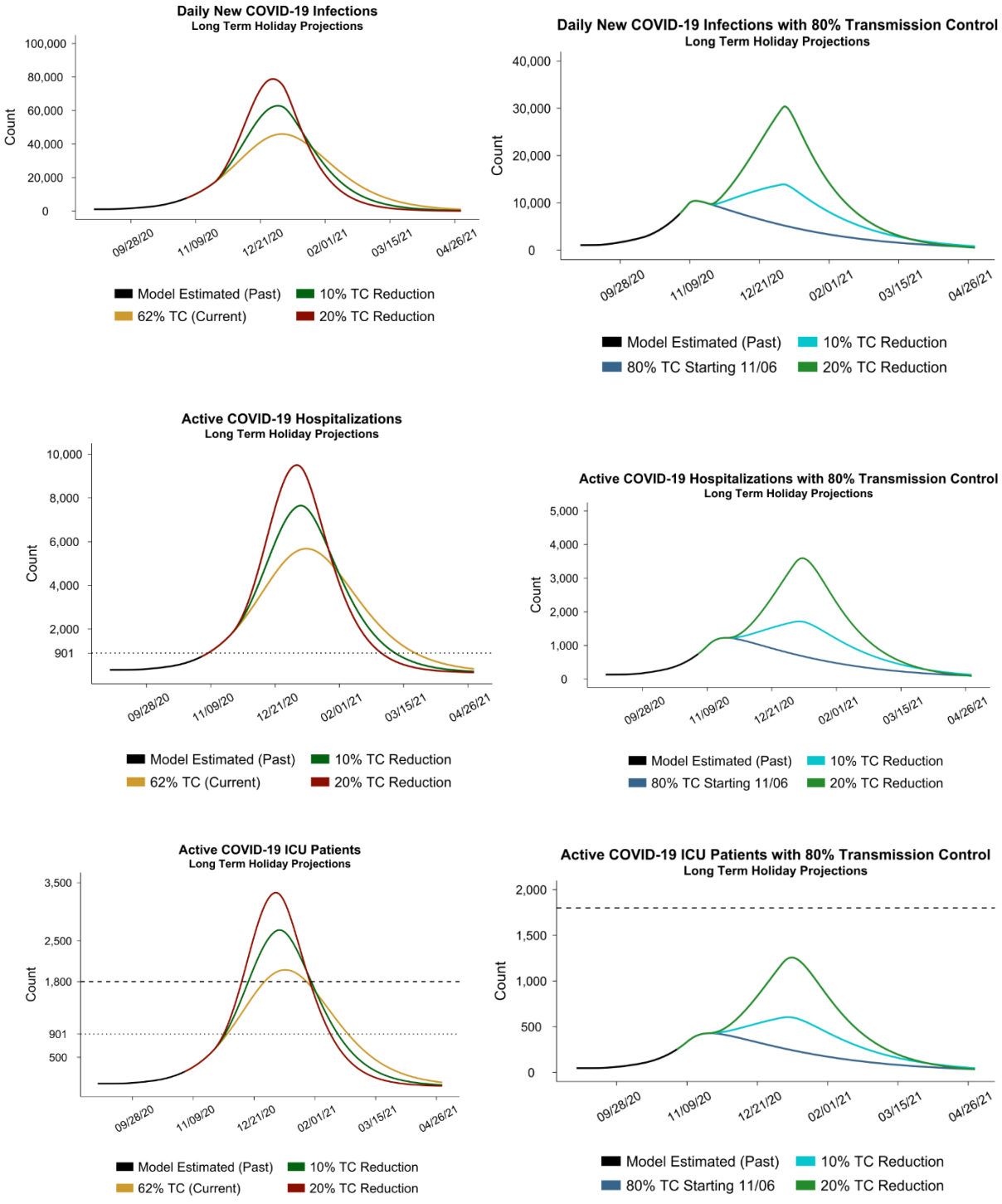
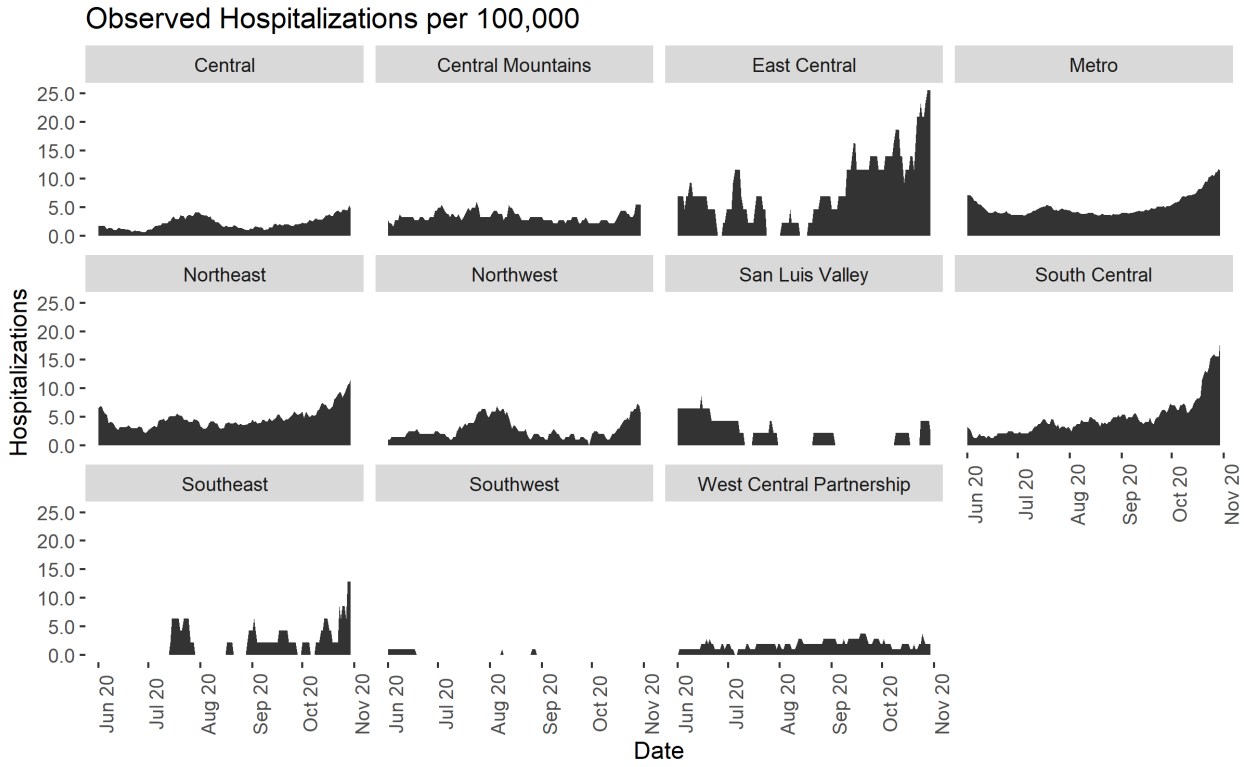


Figure 13. Projected daily count of new infections (top), hospital demand (middle), and intensive care (ICU) demand (bottom) assuming we remain at our current trajectory (62%) until 11/20 (left) or switch to 80% TC on 11/06/2020 (right), with a 10% or 20% relative decrease in transmission control levels over the winter holidays shown. Decrease in transmission control around the winter holidays is assumed to begin 11/20/2020 and last until 1/03/2021. Dotted lines on the infections and hospitalizations graphs represent the peak model estimated number

of infections in April and July and the peak number of hospitalizations, respectively. Note that the y-axis scales on the figures on the right are different from those on the left due to the large differences in the projected number of infections and hospitalizations.

Variation in Hospitalizations across Colorado and in Metro Denver Counties

There is substantial regional variation within Colorado, with most local public health agency (LPHA) regions (South Central, East Central, Central, Metro, Northeast, Northwest, Southeast) seeing marked increases in hospitalizations, while a few regions (San Luis Valley, Southwest) are stable. In the Metro Area, hospitalizations are increasing in all counties (figure 14, bottom). Figure 15 provides estimates of the effective reproductive number (R_E) over time by LPHA region and also for the Metro Denver counties. There is a clear picture of rising transmission across the state and in the Metro Denver counties.



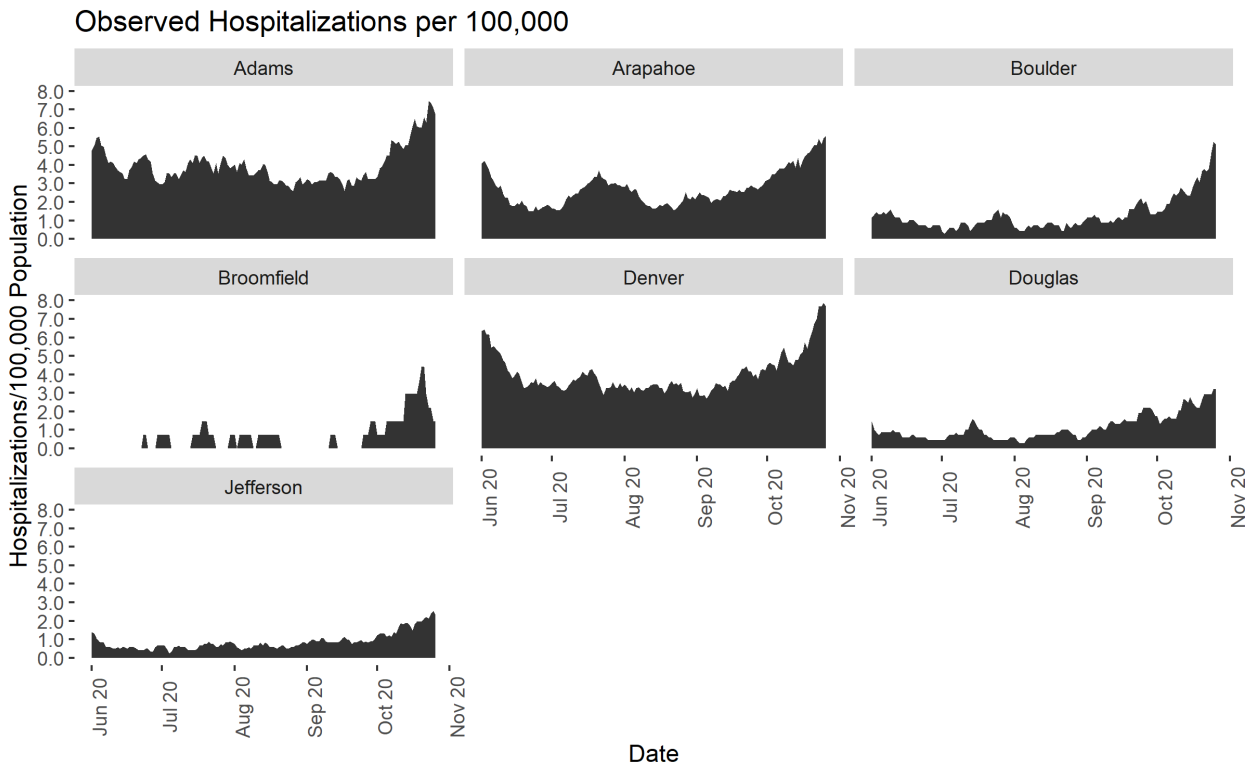
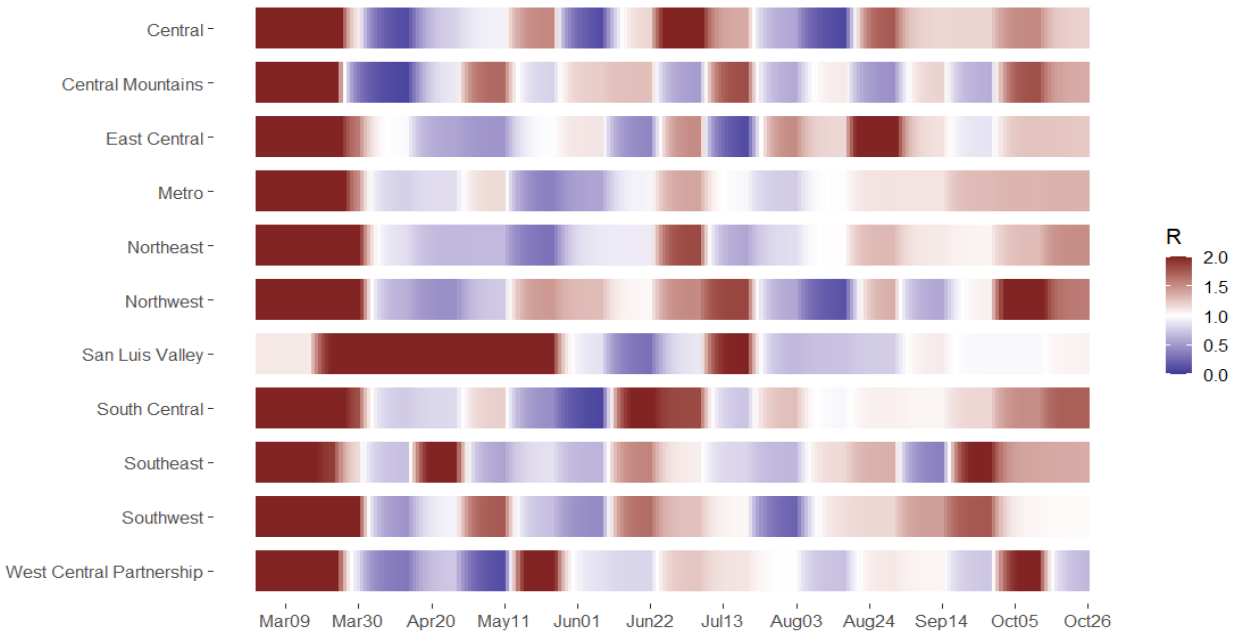


Figure 14. Observed hospitalizations per capita for the 11 LPHA regions in Colorado (top) and for the 7 Metro Denver Counties (Bottom). Data from COPHS hospital census data up to 10/30/2020. Hospitalizations standardized by population estimates from US Census 2020 projections. Hospitalizations since June 1st, 2020 shown. Note that hospitalizations in the past 2-4 days may be under-reports of true hospitalizations and underreporting may vary by region.



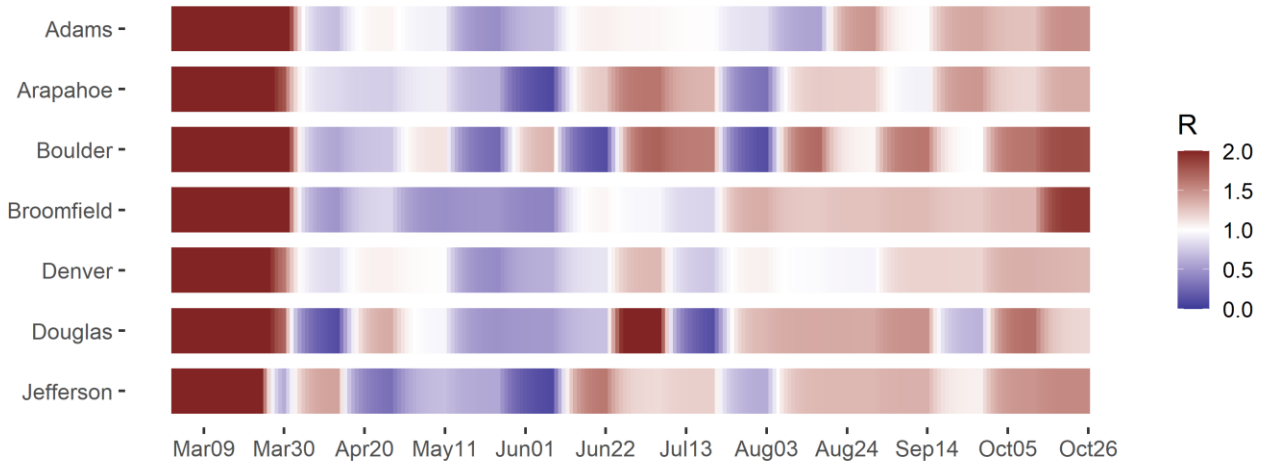


Figure 15. Estimated effective reproductive number for the 11 LPHA regions (top) and the 7 Metro Denver Counties (bottom) using COVID-19 hospitalization data through October 26th.

Table 3. Re and prevalence estimates by county for the Denver metro region for two time points.

	Adams	Arapahoe	Boulder	Broomfield	Denver	Douglas	Jefferson
October 1st, 2020							
Prevalence per 100,000 pop (1)	591	436	215	191	549	191	132
Prevalence per 100,000 pop (2)	762	548	279	230	664	237	185
R_e (1)	1.31	1.25	1.47	1.31	1.32	1.37	1.37
October 26th, 2020							
Prevalence per 100,000 pop (1)	1214	741	751	561	1035	399	325
Prevalence per 100,000 pop (2)	1357	987	939	270	1463	422	456
R_e (1)	1.50	1.38	1.82	1.91	1.32	1.18	1.53

Appendix

Code for our model is available on GitHub: https://github.com/agb85/covid-19

Model simulations evaluating the potential impact of interventions can be generated using our app: https://cucovid19.shinyapps.io/colorado/. This site also includes detailed documentation of our model. The app is updated weekly to reflect our most recent parameter estimates.

Appendix Table A1. Estimated model parameters based on fitting our model output of total hospitalizations to reported hospitalizations in Colorado. The new "TR" model includes a single transmission control parameter that accounts for all reduction in effective contacts as a result of all policy and behavior changes to reduce transmission.

	Range of possible values	Fitted value, TC model	Fit using data through
Transmission control†			
Estimated transmission control level over past three weeks, 09/28 – 10/20	0-99%	65%	11/02
Estimated current transmission control level, 10/12 – 10/20	0-99%	62% (95% CI: 58%, 65%)	11/02
Transmission parameters			
The rate of infection (beta)	0.2 - 0.6††	0.48	06/24
Ratio of infectiousness for symptomatic vs. asymptomatic individuals (lambda)	1.0 - 4.0††	1.39	06/24

†Two-week Transmission control parameters are estimated weekly and averaged over time period of interest.
††The range of potential parameter values for the rate of infectiousness for symptomatic vs. asymptomatic individuals [1, 2] are based on the literature, and for the rate of infection, were obtained from the MIDAS Online COVID-19 compilation of parameter estimates [3].

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