Network Systems Science & Advanced Computing

Biocomplexity Institute & Initiative

University of Virginia

Estimation of COVID-19 Impact in Virginia

November 3rd, 2020

(data current to November 3rd)

Biocomplexity Institute Technical report: TR 2020-134

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About Us

- Biocomplexity Institute at the University of Virginia
  - Using big data and simulations to understand massively interactive systems and solve societal problems
- Over 20 years of crafting and analyzing infectious disease models
  - Pandemic response for Influenza, Ebola, Zika, and others

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Overview

- **Goal**: Understand impact of COVID-19 mitigations in Virginia
- **Approach:**
  - Calibrate explanatory mechanistic model to observed cases
  - Project infections through December
  - Consider a range of possible mitigation effects in "what-if" scenarios
- **Outcomes:**
  - Ill, Confirmed, Hospitalized, ICU, Ventilated, Death
  - Geographic spread over time, case counts, healthcare burdens

Key Takeaways

Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

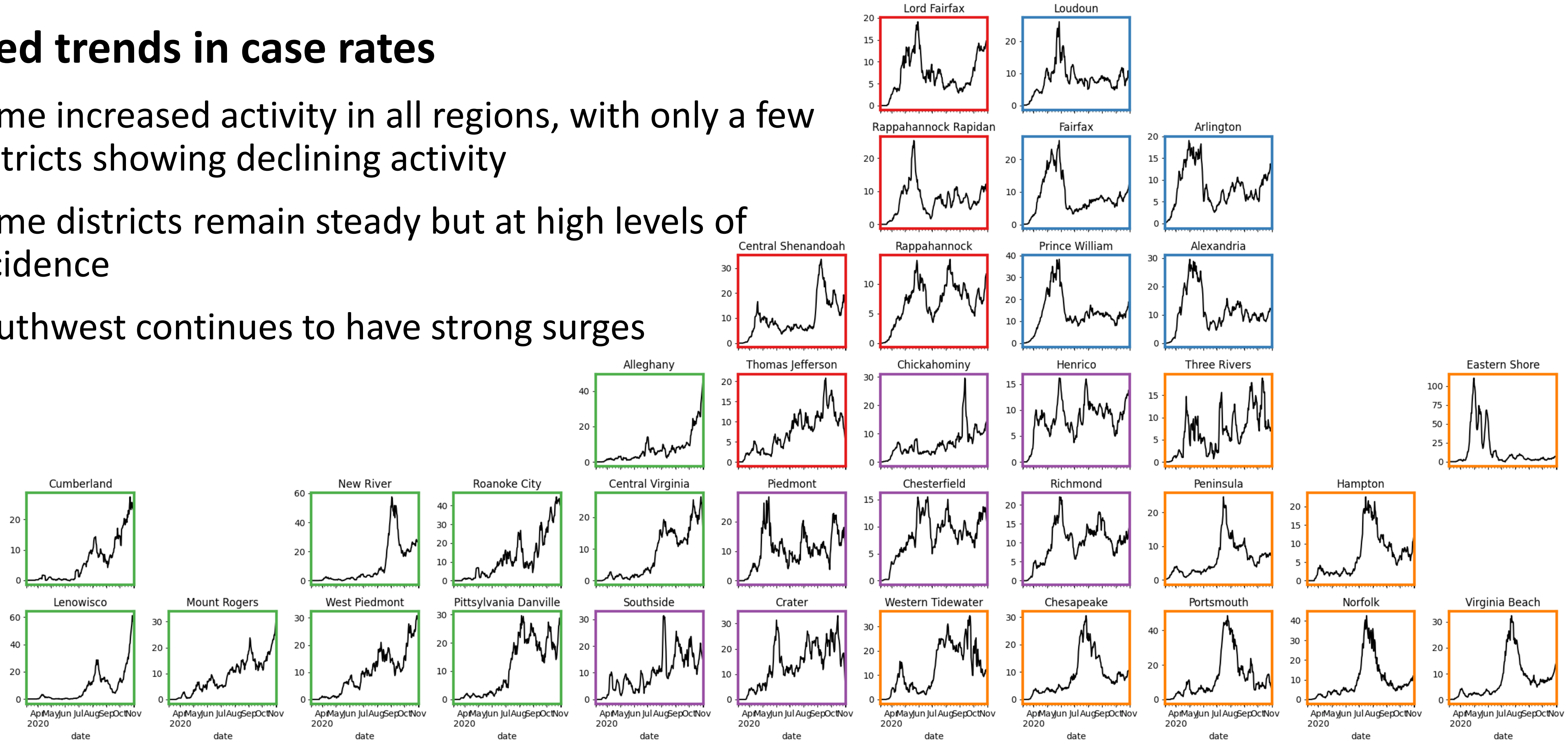
- **Virginia has had significant steady growth which is shared across the commonwealth.**
- VA weekly incidence (14.8/100K) is up though outpaced by the national average (34/100K).
- Projections are mostly up, showing potential for strain on health care system in some regions as early as December.
- Recent updates:
  - Planning Scenarios adjusted, as Adaptive Fitting tracks recent surge, to represent population's ability to exert further control on transmission following Thanksgiving holidays, Nov 26th.
  - Case ascertainment parameters now bounded by updated seroprevalence data.
- The situation is changing rapidly. Models will be updated regularly.

Situation Assessment

Case Rate (per 100k) by VDH District

Mixed trends in case rates

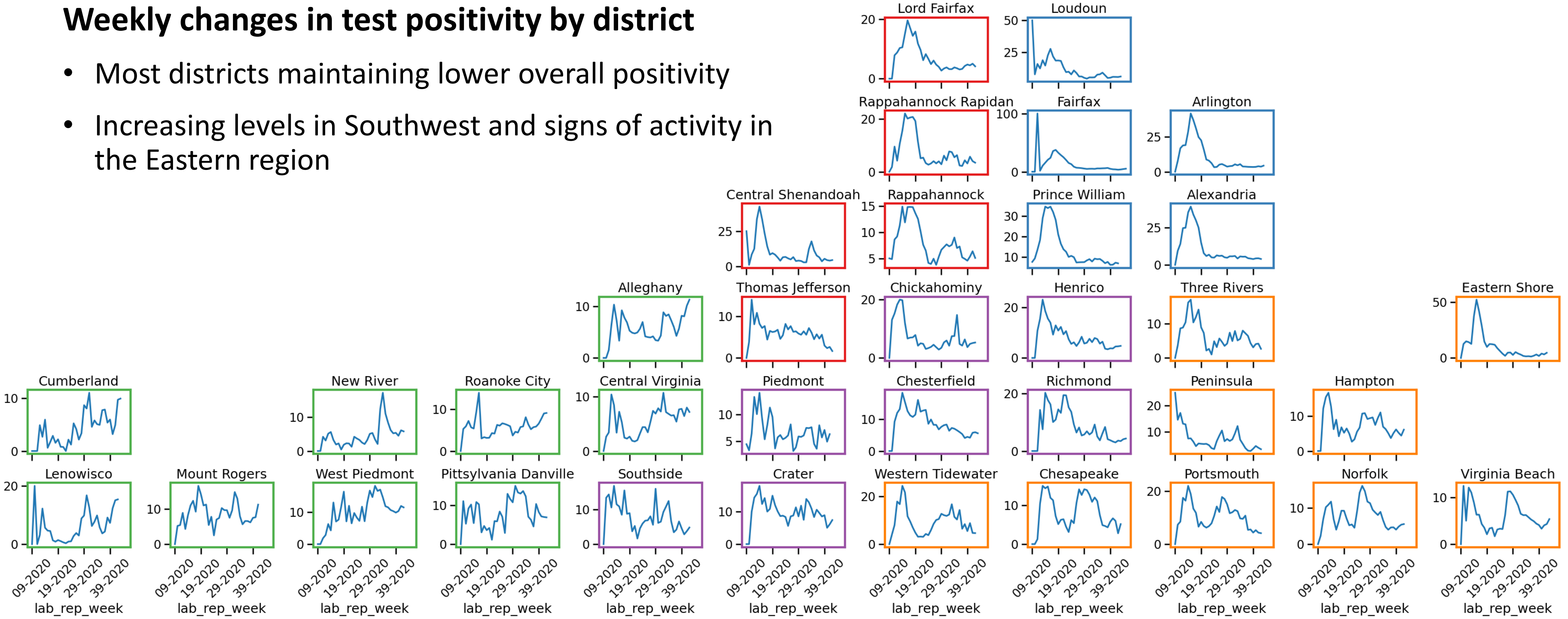
- Some increased activity in all regions, with only a few districts showing declining activity
- Some districts remain steady but at high levels of incidence
- Southwest continues to have strong surges



Test Positivity by VDH District

Weekly changes in test positivity by district

- Most districts maintaining lower overall positivity
- Increasing levels in Southwest and signs of activity in the Eastern region



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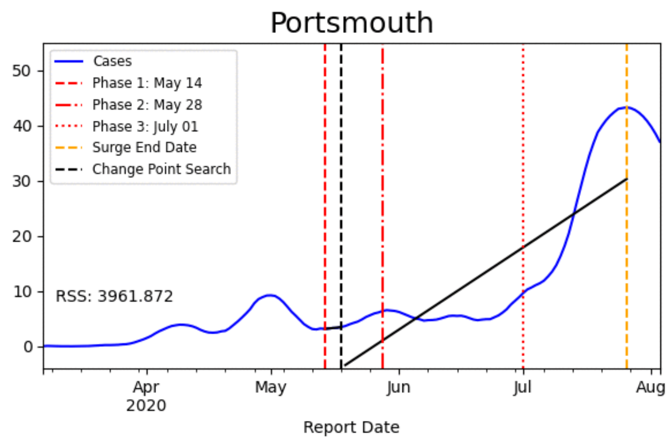
District Trajectories

Goal: Define epochs of a Health District's COVID-19 incidence to characterize the current trajectory

Method: Find recent peak and use hockey stick fit to find inflection point afterwards, then use this period's slope to define the trajectory

Hockey stick fit

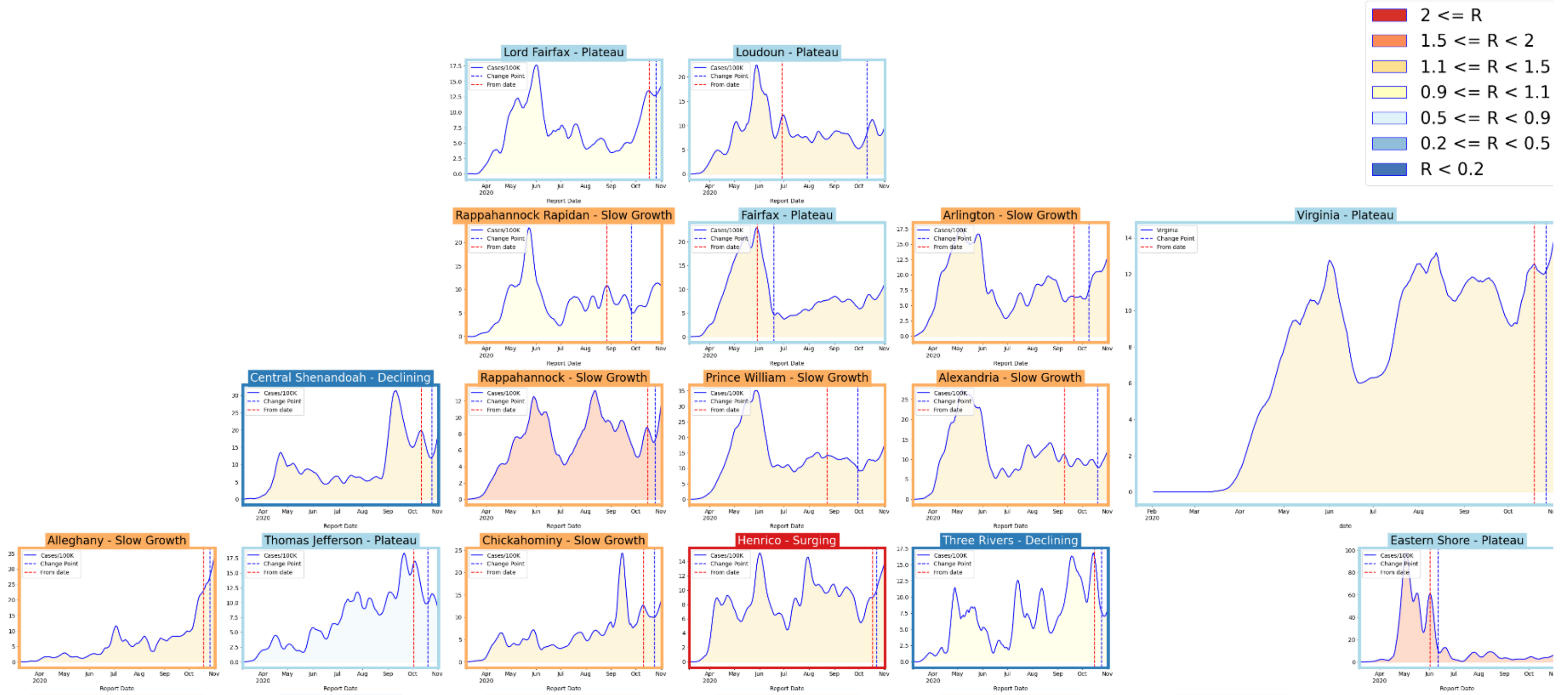


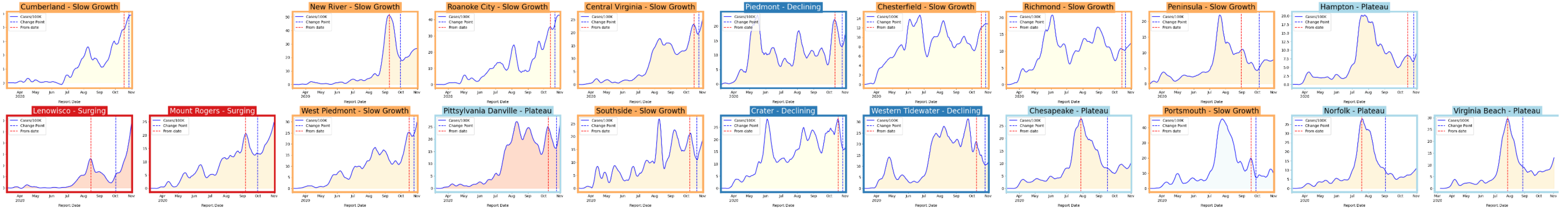
Trajectory	Description	Weekly Case Rate (per 100K) bounds	# Districts (last week)
Declining	Sustained decreases following a recent peak	below -0.9	5 (10)
Plateau	Steady level with minimal trend up or down	above -0.9 and below 0.5	10 (10)
Slow Growth	Sustained growth not rapid enough to be considered a Surge	above 0.5 and below 2.5	17 (11)
In Surge	Currently experiencing sustained rapid and significant growth	2.5 or greater	3 (4)

District Trajectories

Status	# Districts (last week)
Declining	5 (10)
Plateau	10 (10)
Slow Growth	17 (11)
In Surge	3 (4)

Curve shows smoothed case rate (per 100K)
Trajectories of states in label & chart box
Case Rate curve colored by Reproductive





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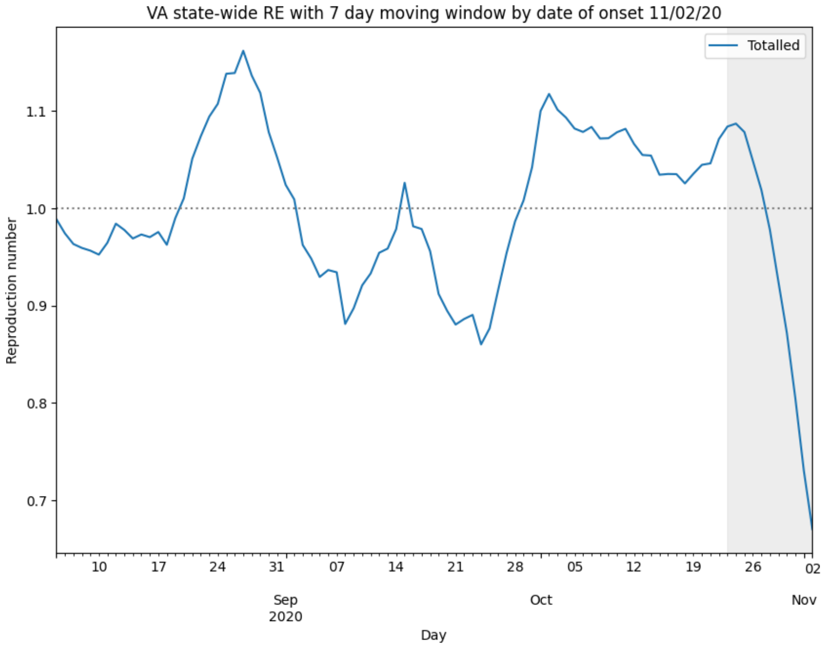
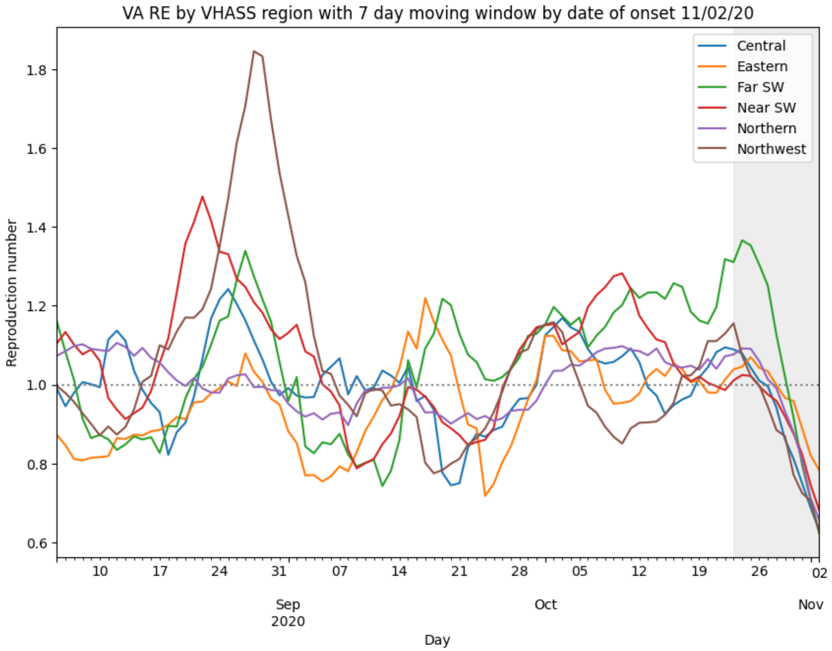
Estimating Daily Reproductive Number

October 24th Estimates

Region	Current R_e	Diff Last Week
State-wide	1.087	0.119
Central	1.079	0.168
Eastern	1.046	0.004
Far SW	1.366	0.136
Near SW	1.025	0.049
Northern	1.092	0.122
Northwest	1.074	0.157





Methodology

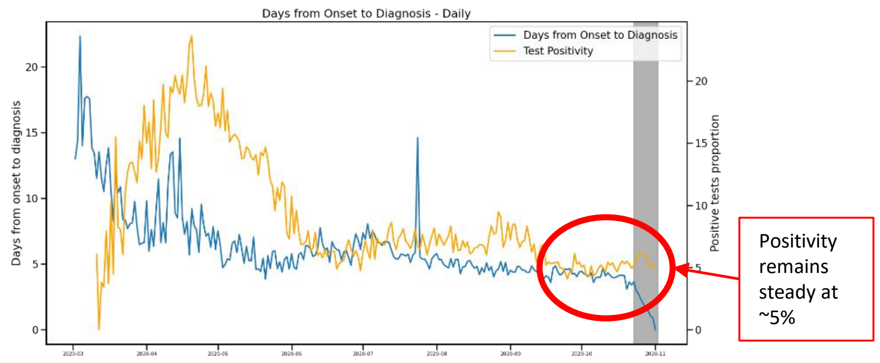
- Wallinga-Teunis method (EpiEstim[1]) for cases by date of onset
- Serial interval: 6 days (2 day std dev)
- Recent estimates may be unstable due to backfill

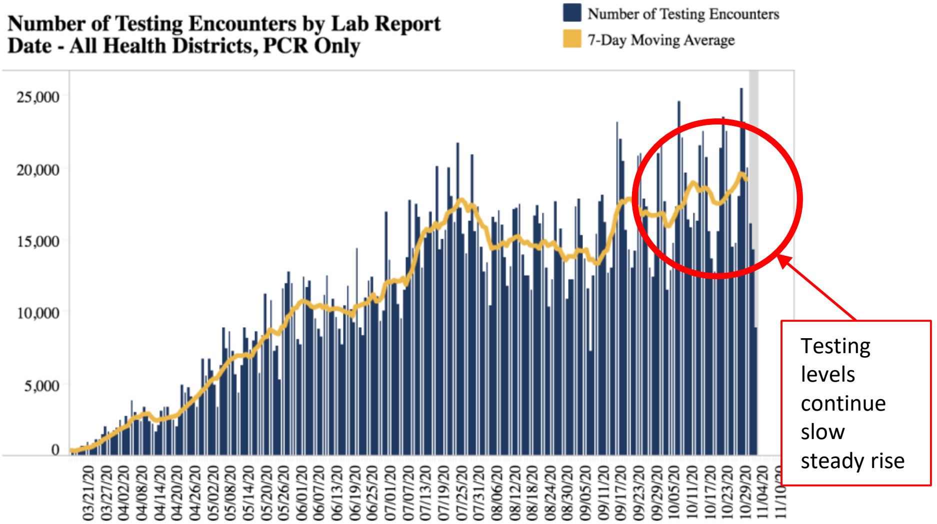
1. Anne Cori, Neil M. Ferguson, Christophe Fraser, Simon Cauchemez. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. American Journal of Epidemiology, Volume 178, Issue 9, 1 November 2013, Pages 1505–1512, https://doi.org/10.1093/aje/kwt133

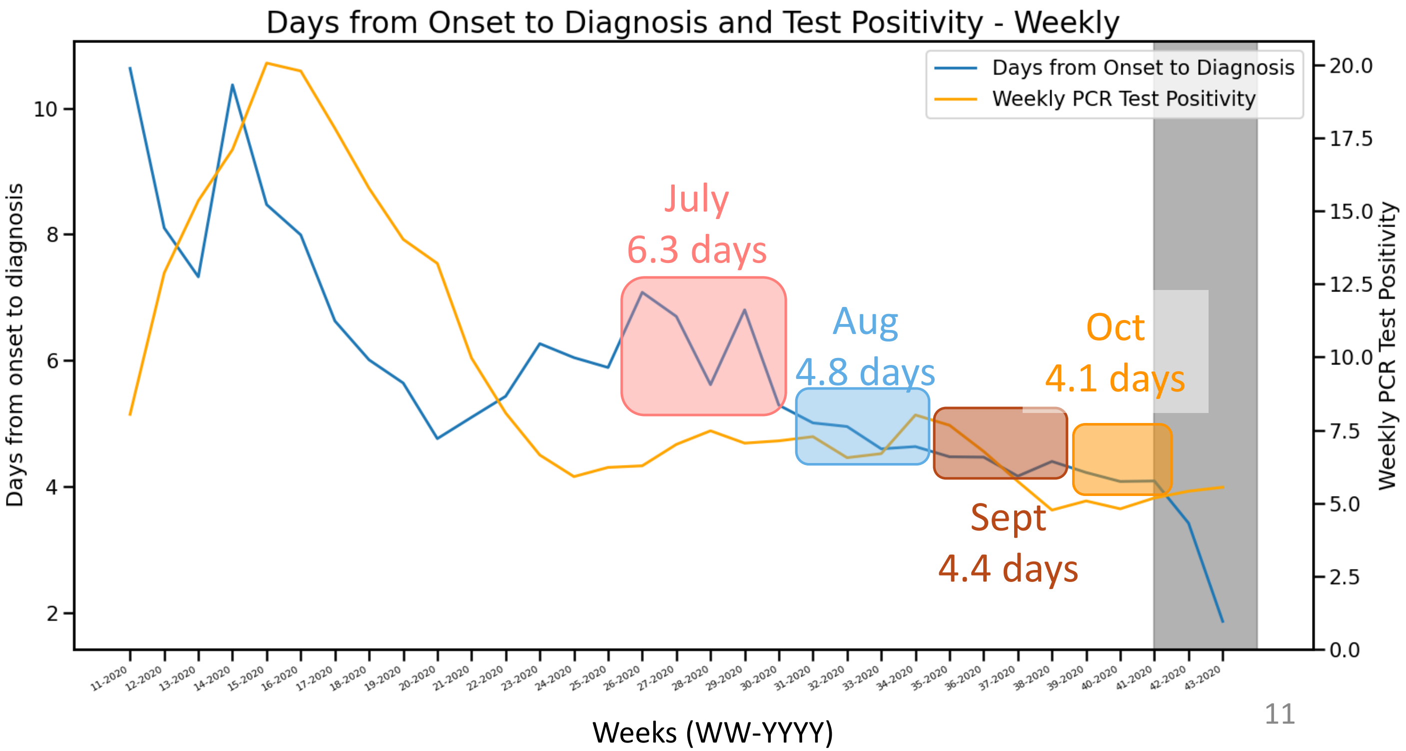
Changes in Case Detection

Timeframe (weeks)	Mean days	% difference from overall mean
April (13-16)	8.5	49%
May (17-21)	5.6	-2%
June (22-25)	5.9	3%
July (26-30)	6.3	10%
Aug (31-34)	4.8	-16%
Sept (35-38)	4.4	-24%
Oct (39-41)	4.1	-28%
Overall (13-37)	5.7	0%

Test positivity vs. Onset to Diagnosis

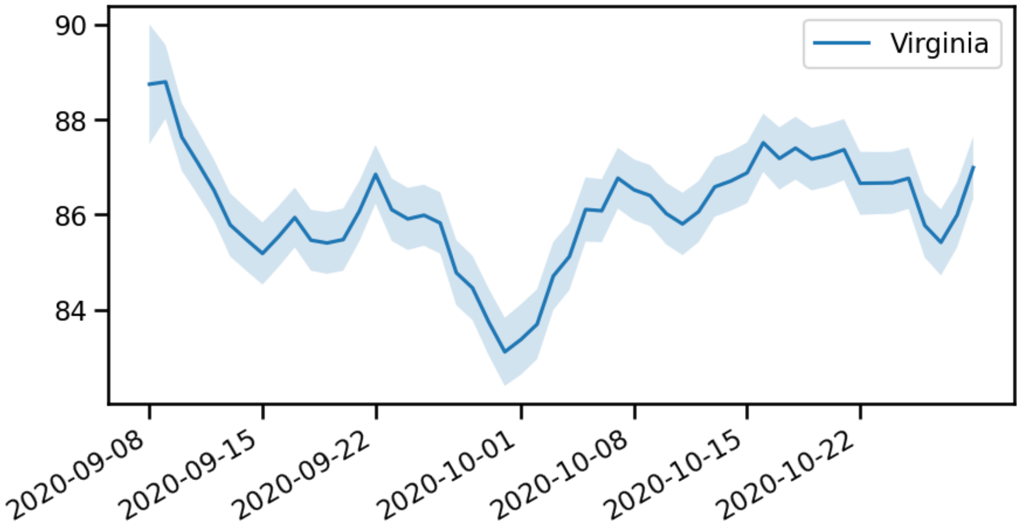






Accessed 2:00pm November 3, 2020
https://www.vdh.virginia.gov/coronavirus/

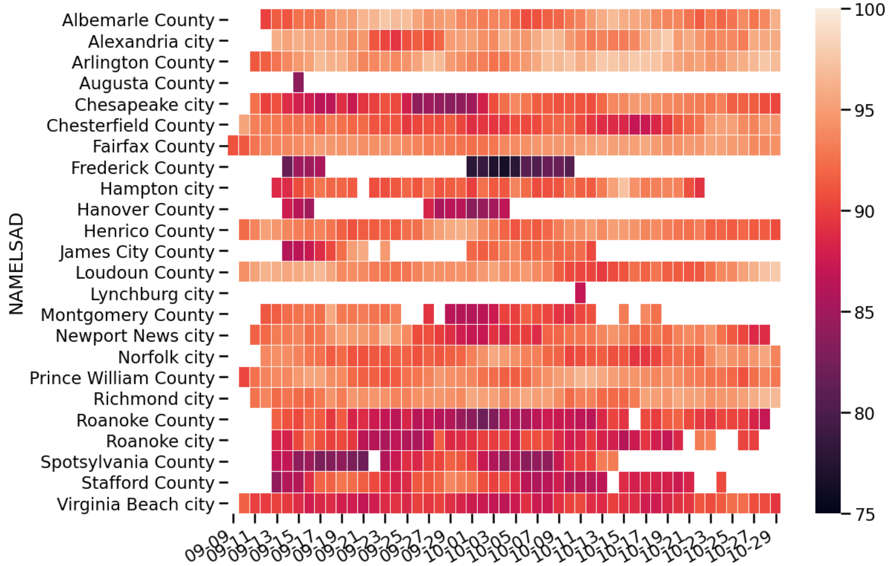
Mask usage in Virginia



State level mask usage as reported via Facebook surveys over the past month shows ranges from 83% to 89%

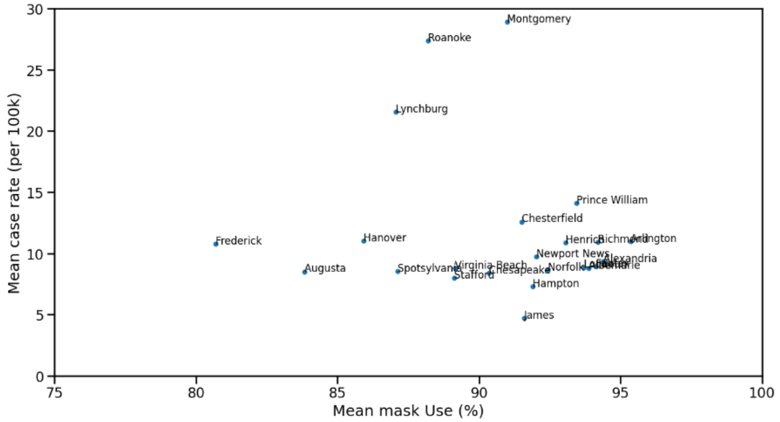
- Relatively stable over time
- Limited variance across the commonwealth
- ~3000 daily responses from VA

Data Source: https://covidcast.cmu.edu



Some county level fluctuations since beginning of Sept., though data quality may be affected by sample sizes.

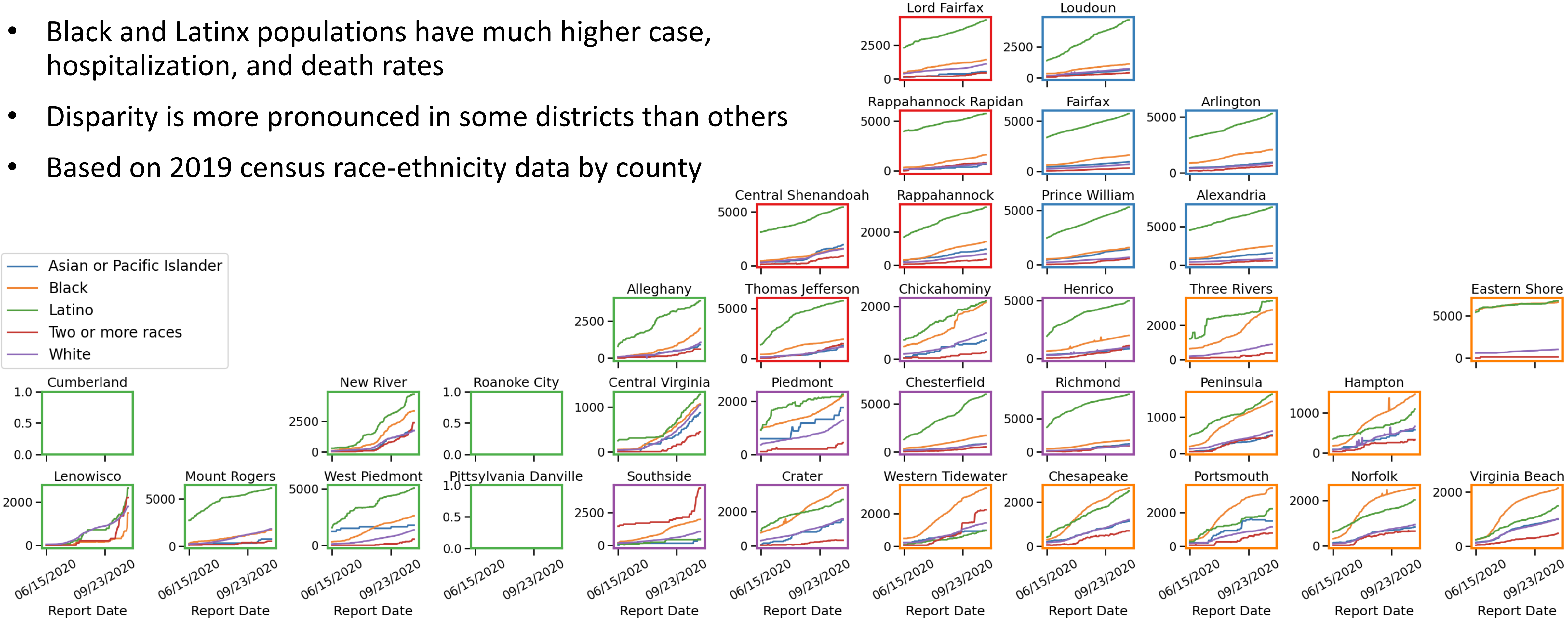
Correlations seen at national level with mask use and case rate not emerging across VA counties, reflecting high use across commonwealth



Race and Ethnicity Attack Rates (per 100K)

Cumulative Race and Ethnicity Attack Rates (per 100k)

- Black and Latinx populations have much higher case, hospitalization, and death rates
- Disparity is more pronounced in some districts than others
- Based on 2019 census race-ethnicity data by county



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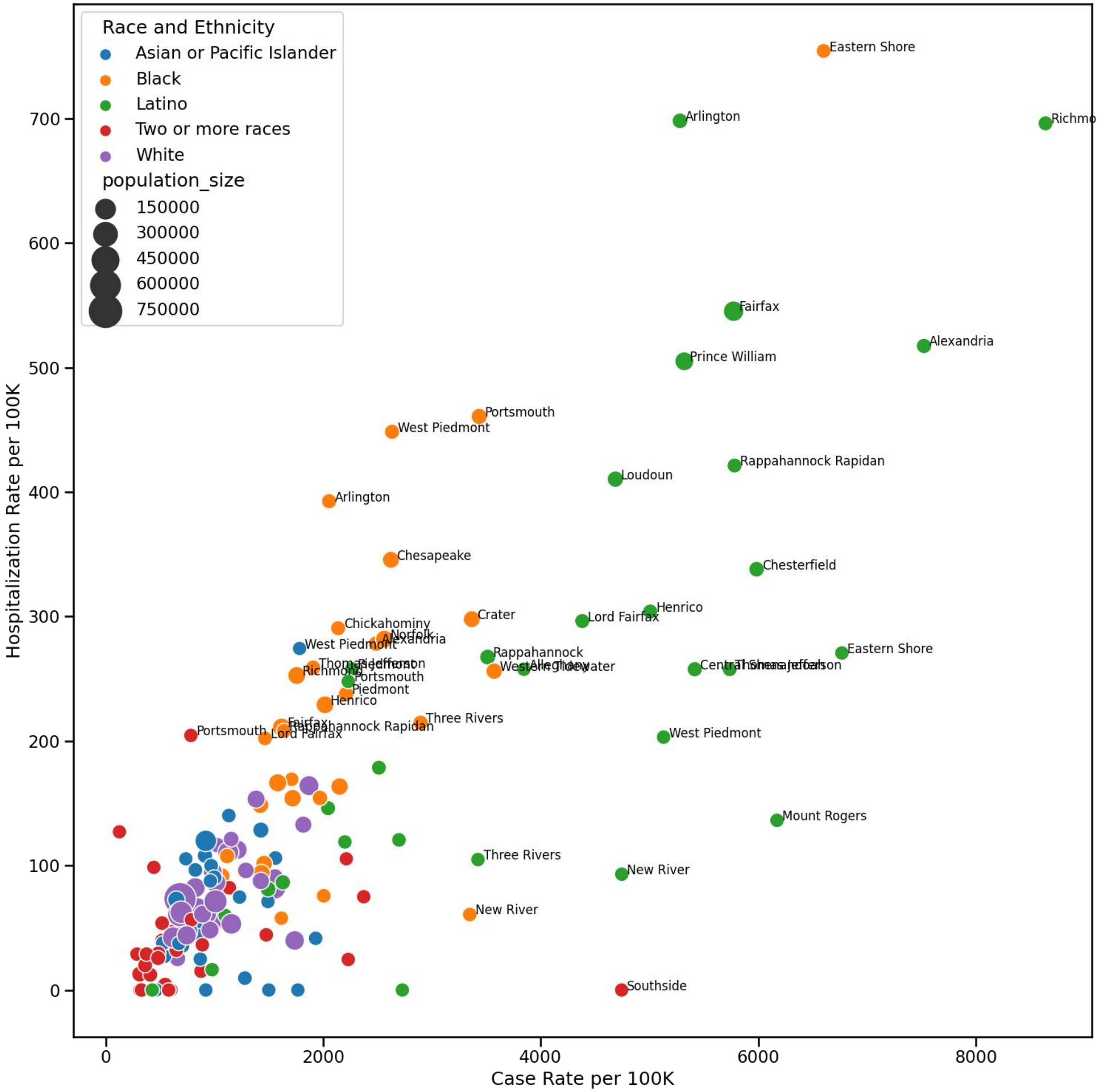
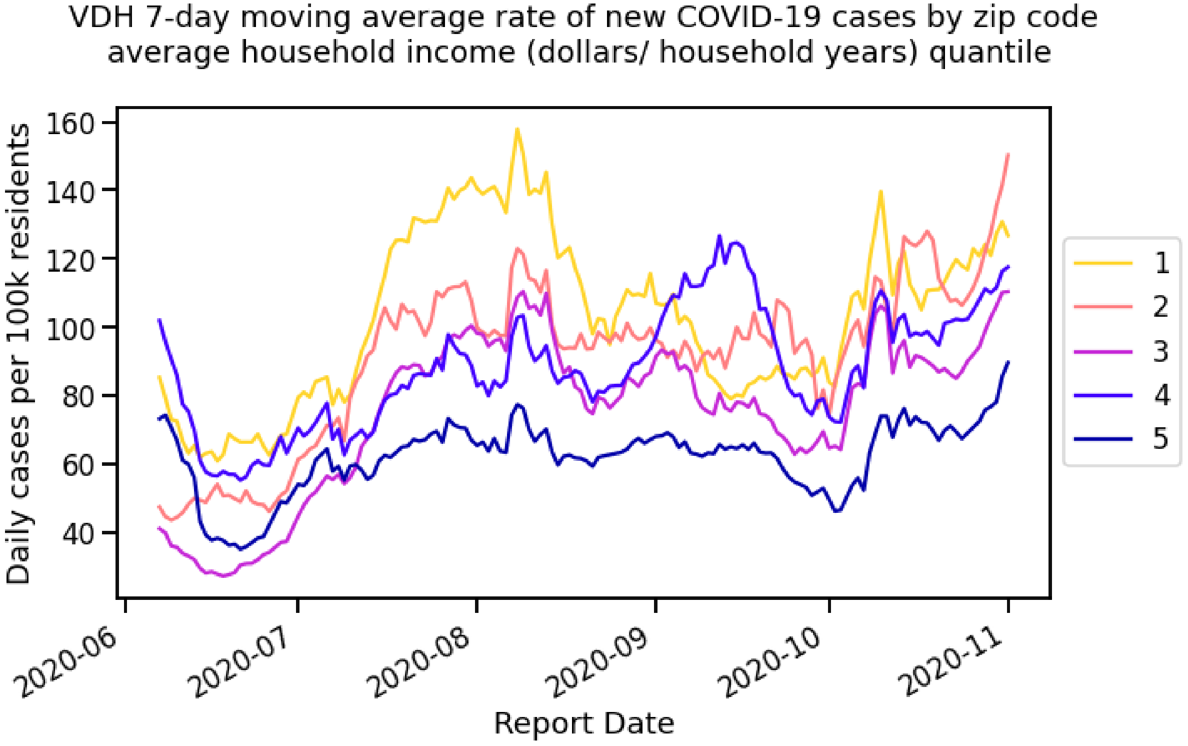
Race and Ethnicity cases per 100K

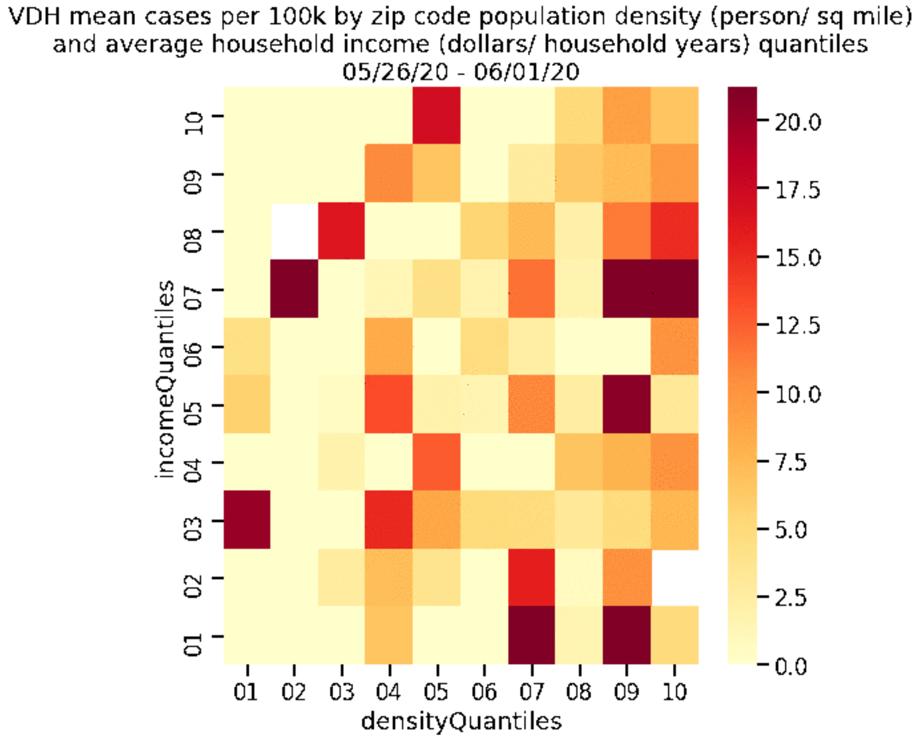


Rates per 100K of each Racial-Ethnic population by Health District

- Each Health District's Racial-Ethnic population is plotted by their Hospitalization and Case Rate
- Points are sized based on their overall population size
- Overlapping labels removed for clarity

Impact across Density and Income



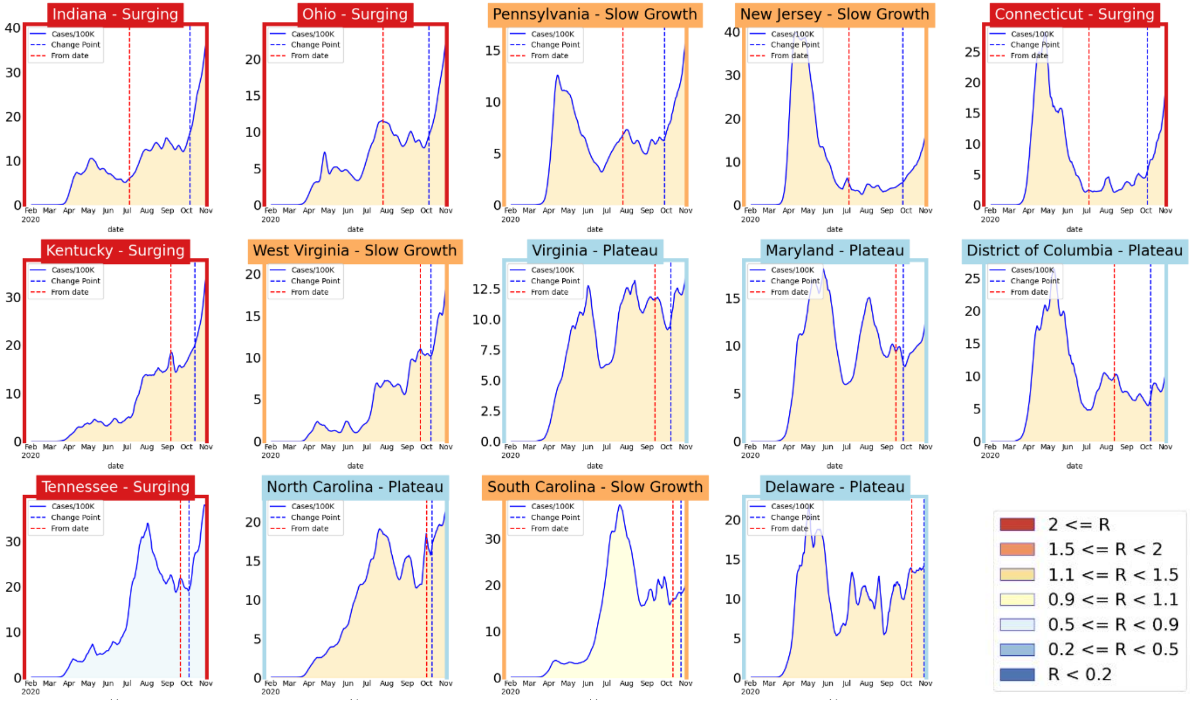


Shift back to higher income zip codes partially driven by surges in areas surrounding universities, which has since receded with the lower 40% bearing higher rates of disease

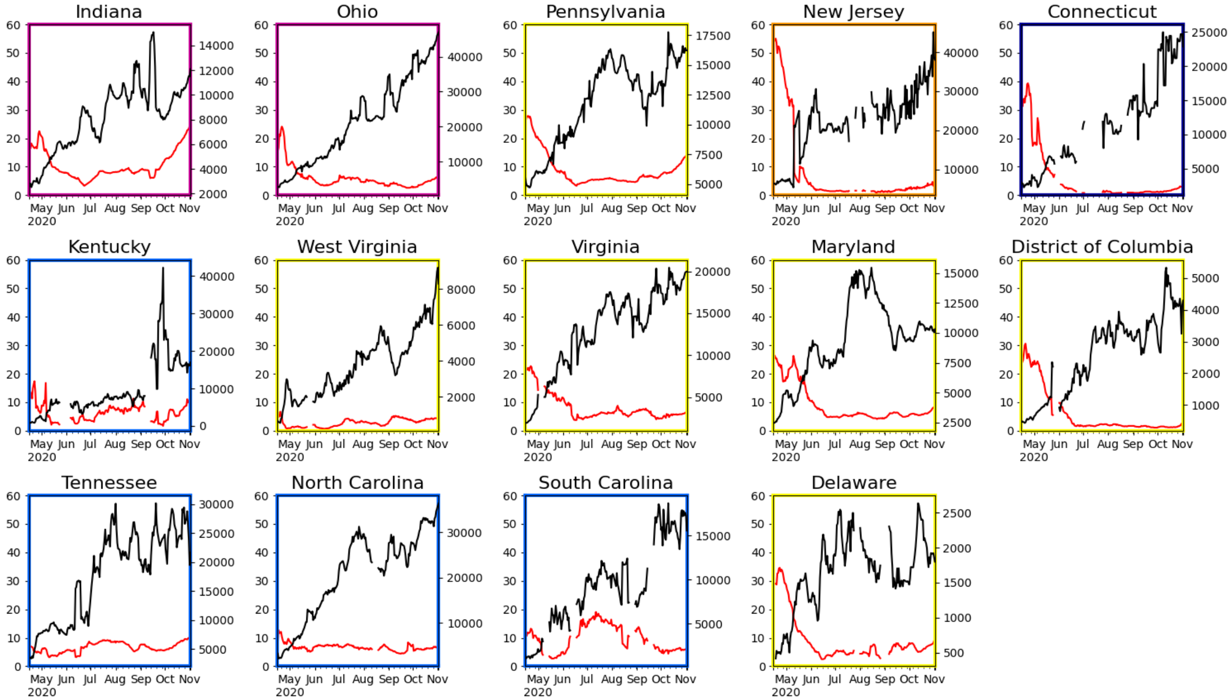
Can see the evolution from denser and wealthier zip codes to poorer and less dense zip codes, then back to denser wealthier zip codes, with an additional shift back again to poorer and less dense areas

Other State Comparisons

Trajectories of States



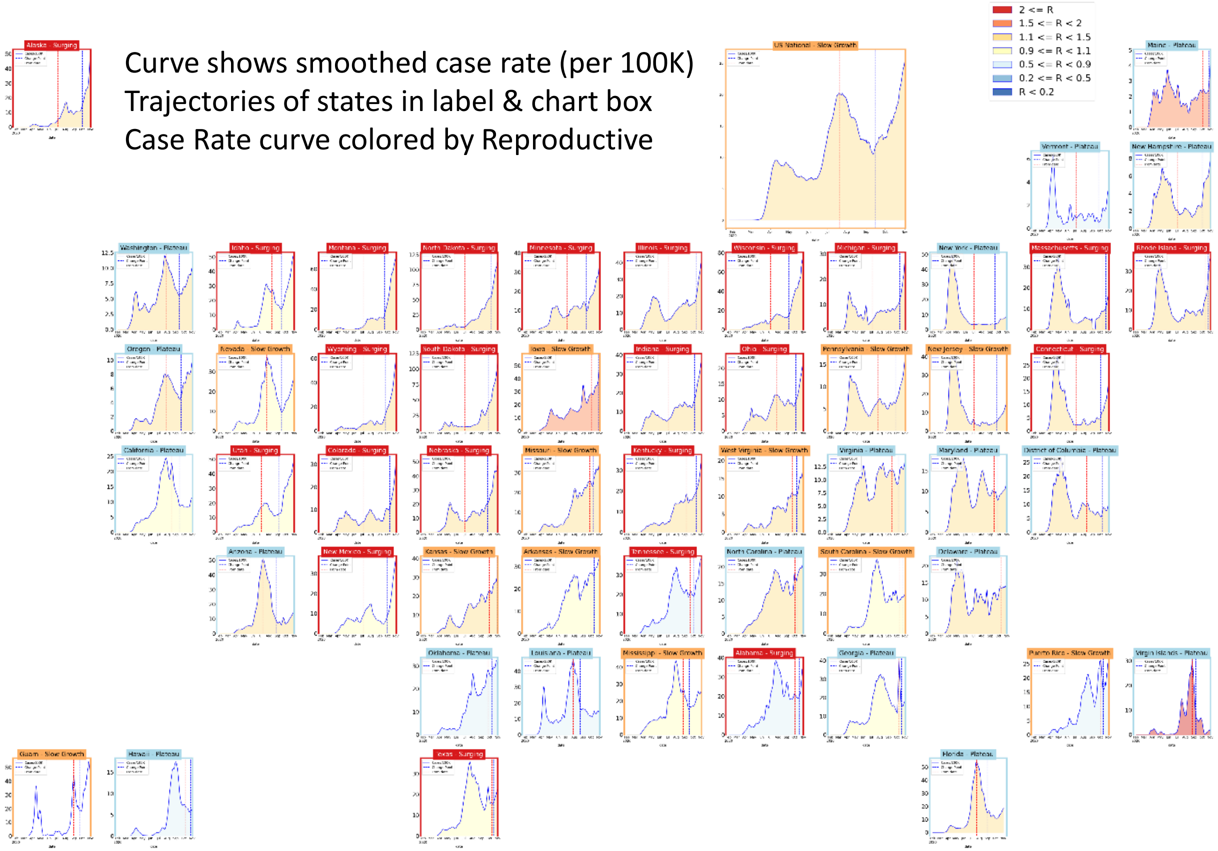
Tests per Day and Test Positivity

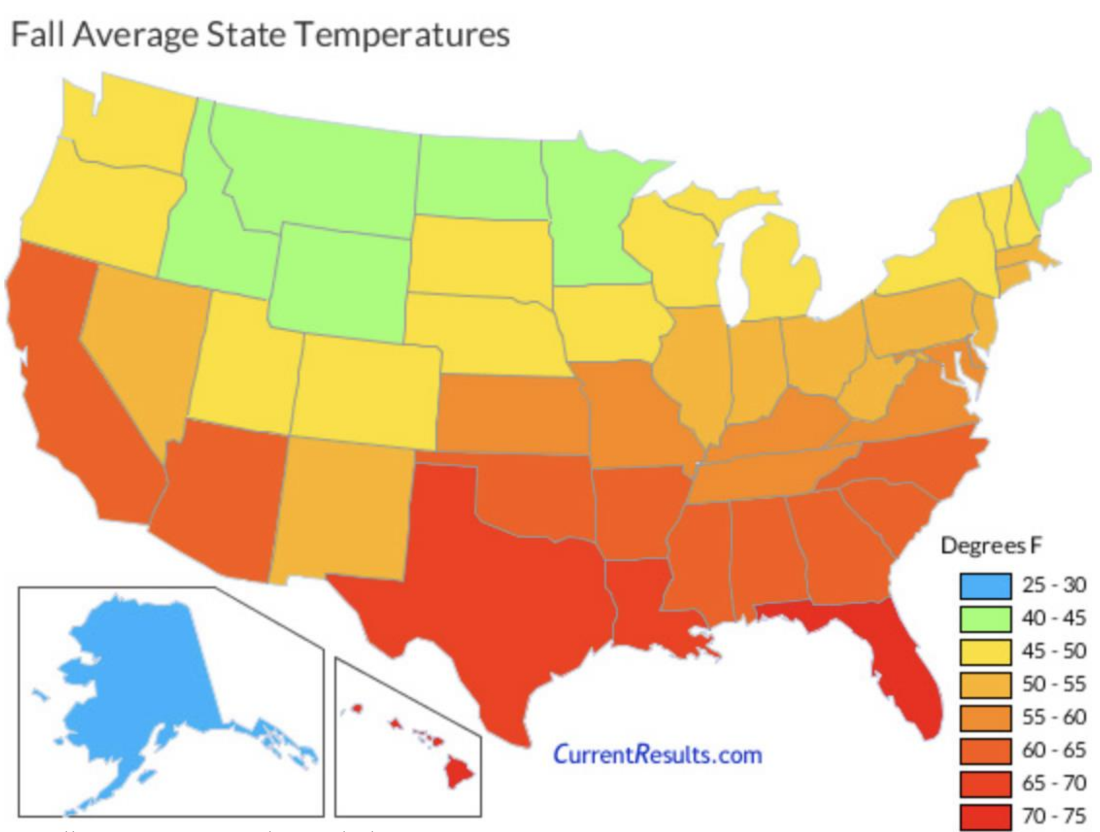


- VA and other mid-Atlantic states in plateaus with signs of growth
- KY, OH, CT join TN and IN in surge (among 23 in all of US)
- All surrounding states in Slow Growth or Plateaued but trending upward

- Test positivity mixed, VA's rate has start slowly growing.
- Testing volumes remain steady and relatively high in most states

Growth Associated with Temperature and Humidity





https://www.currentresults.com/Weather/US/state-temperature-maps-seasonal.php

- As weather cools and humidity drops, COVID-19 survival and chance of transmission may rise
- This may be contributing, with other factors, to the rise in cases in plains and Midwest as well as Northeast

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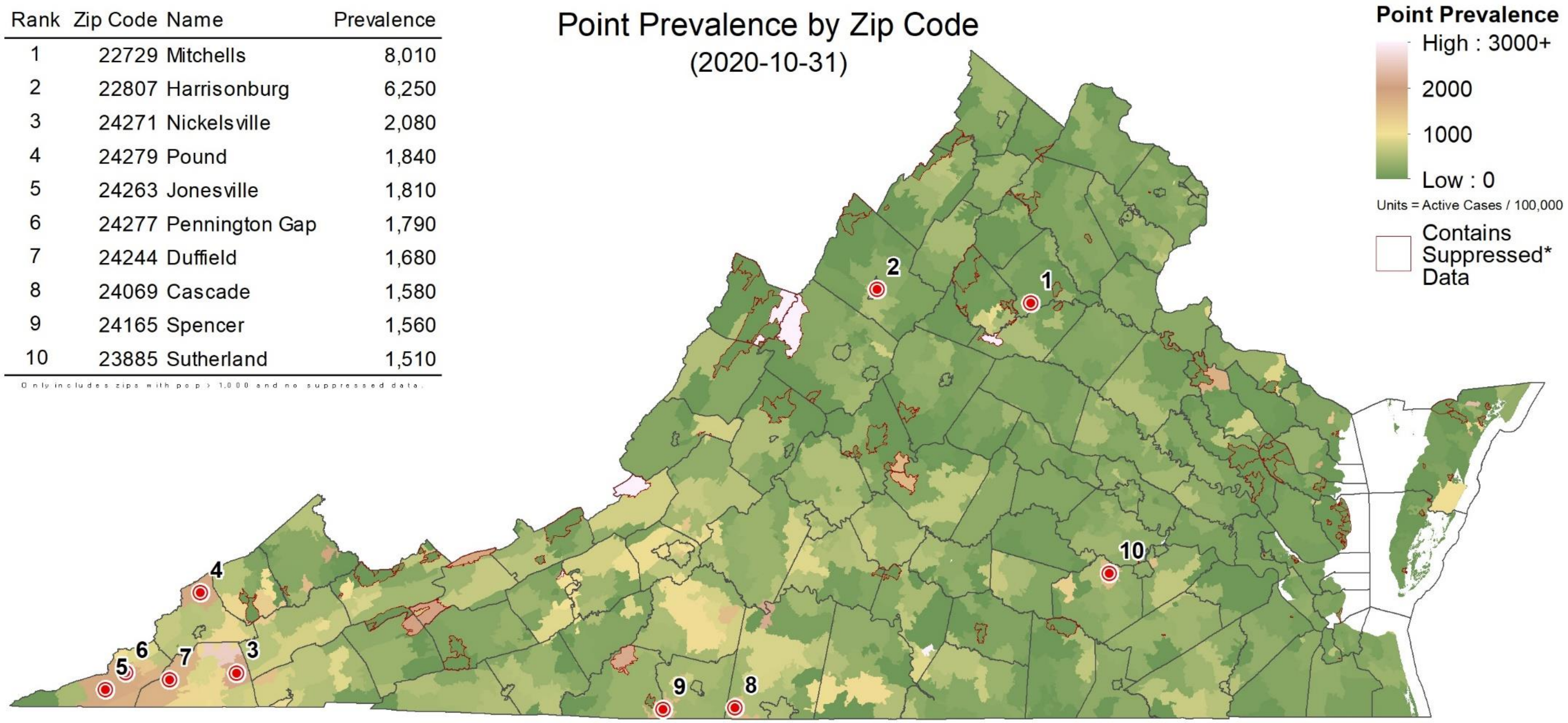
Zip code level weekly Case Rate (per 100K)

Case Rates in the last week by zip code

- Concentrations of very high prevalence in some zip codes
- Trend back towards very high rates in a few zips and lower in surrounding areas
- Southwest has considerable concentration of high prevalence zips
- Some counts are low and suppressed to protect anonymity, those are shown in white

Rank	Zip Code	Name	Prevalence
1	22729	Mitchells	8,010
2	22807	Harrisonburg	6,250
3	24271	Nickelsville	2,080
4	24279	Pound	1,840
5	24263	Jonesville	1,810
6	24277	Pennington Gap	1,790
7	24244	Duffield	1,680
8	24069	Cascade	1,580
9	24165	Spencer	1,560
10	23885	Sutherland	1,510

Only includes zips with pop > 1,000 and no suppressed data.



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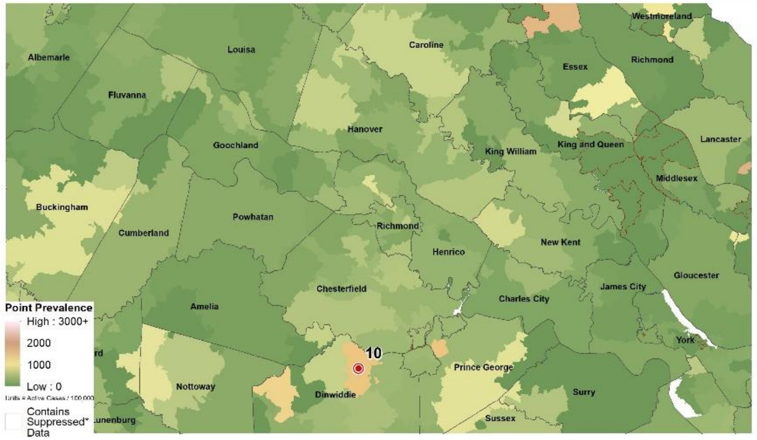
Zip code level weekly Case Rate (per 100K)

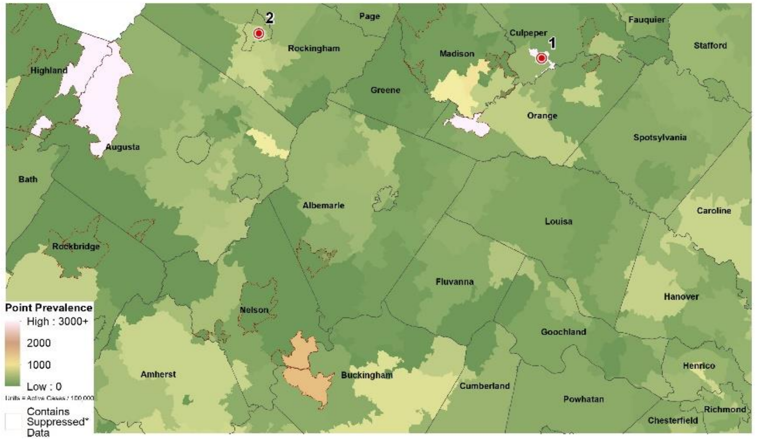
Richmond

Point Prevelence by Zip Code
2020-10-25 to 2020-10-31



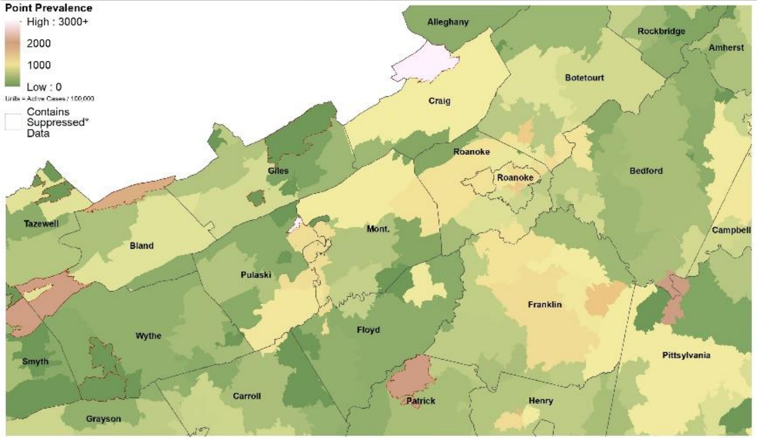
Albemarle

Point Prevelence by Zip Code
2020-10-25 to 2020-10-31



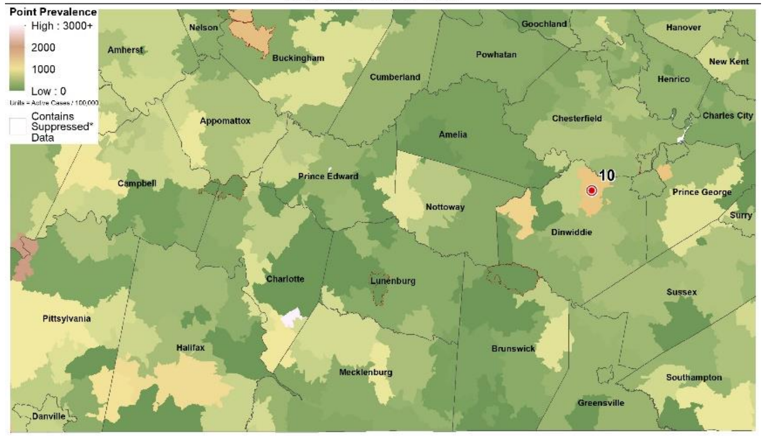
New River Valley

Point Prevelence by Zip Code
2020-10-25 to 2020-10-31



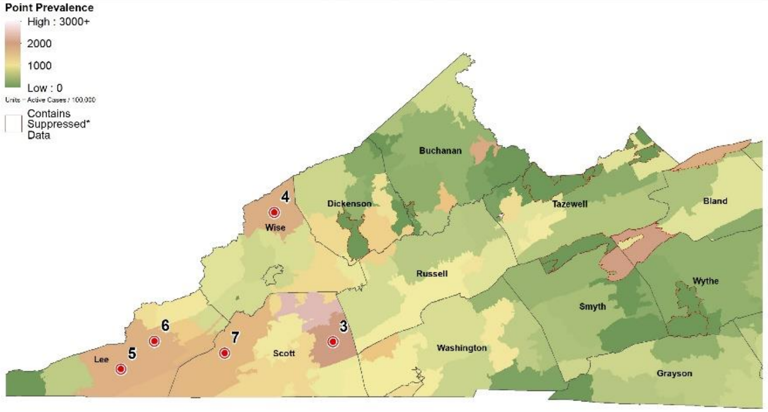
Southside

Point Prevelence by Zip Code
2020-10-25 to 2020-10-31



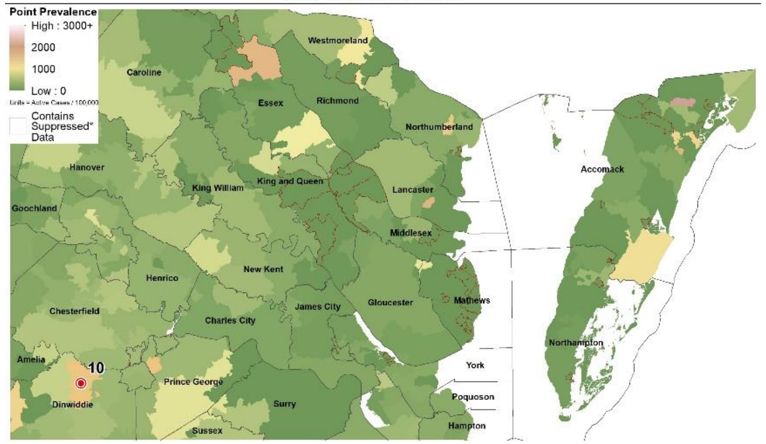
Far Southwest

Point Prevelence by Zip Code
2020-10-25 to 2020-10-31



Three Rivers

Point Prevelence by Zip Code
2020-10-25 to 2020-10-31



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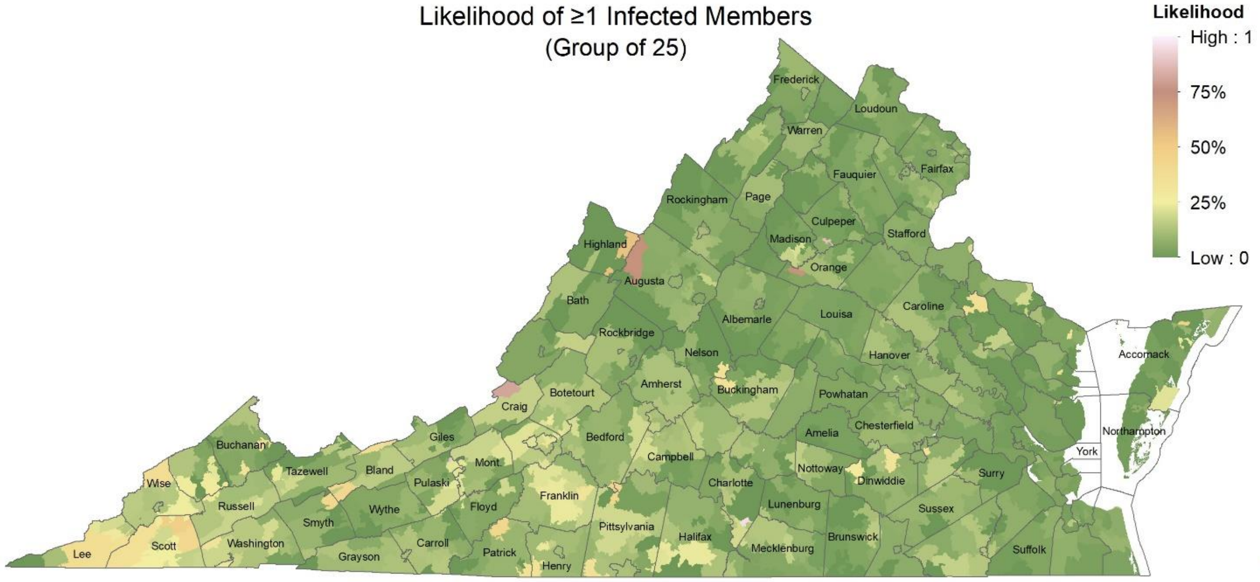
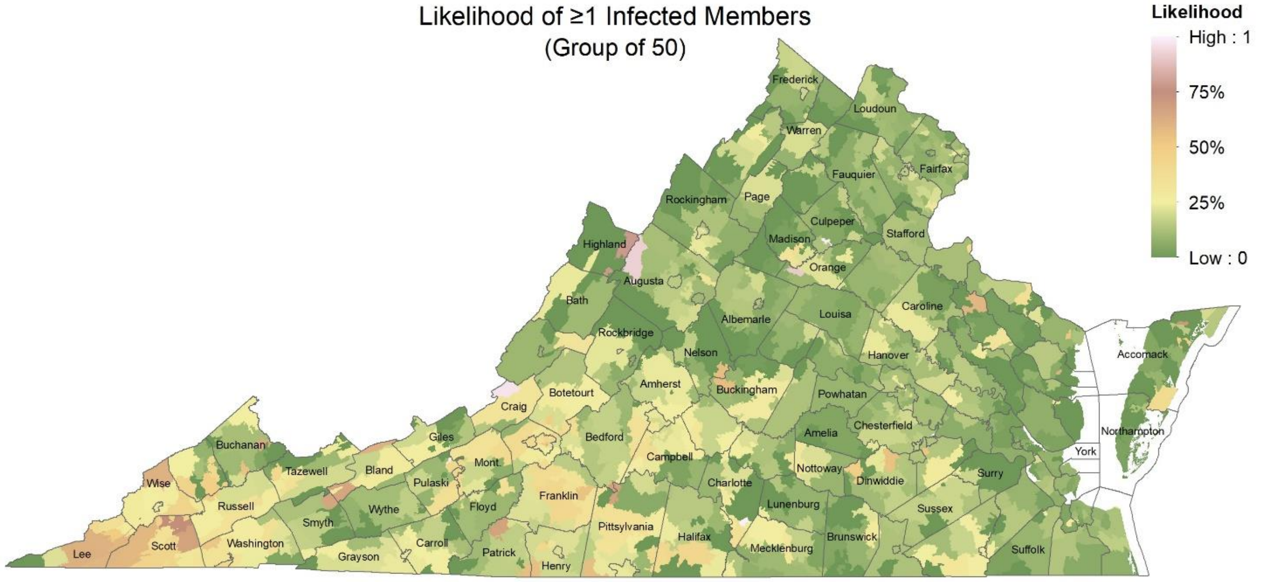
Risk of Exposure by Group Size

Case Prevalence in the last week by zip code used to calculate risk of encountering someone infected in a gathering of randomly selected people (group size 25 or 50)

- Assumes 3 undetected infections per confirmed case (ascertainment rate from recent seroprevalence survey)
- Moderate risk for groups of 50 across the commonwealth, especially in the southern half of the state
- Some zip codes have high likelihood of exposure even in groups of 25



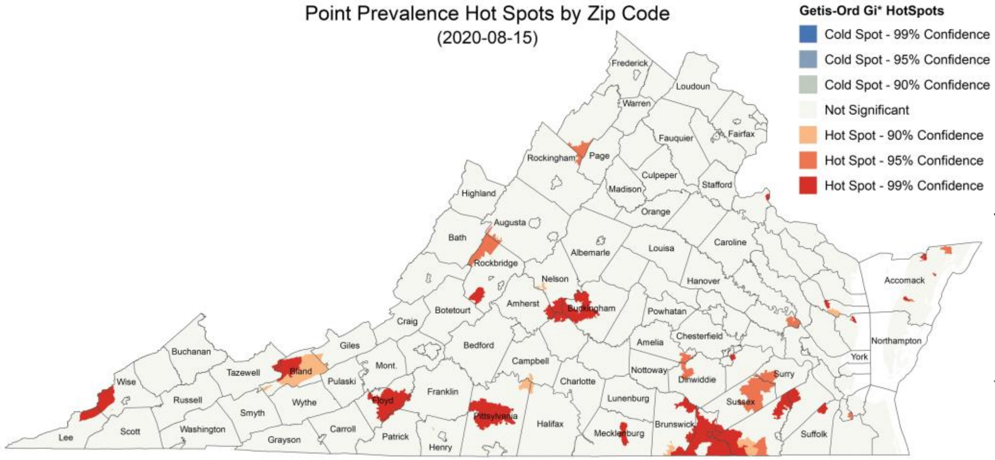
Based on zip code point prevelence for week ending 2020-10-31



Based on zip code point prevelence for week ending 2020-10-31

Zip Code Hot Spots

Previous weeks



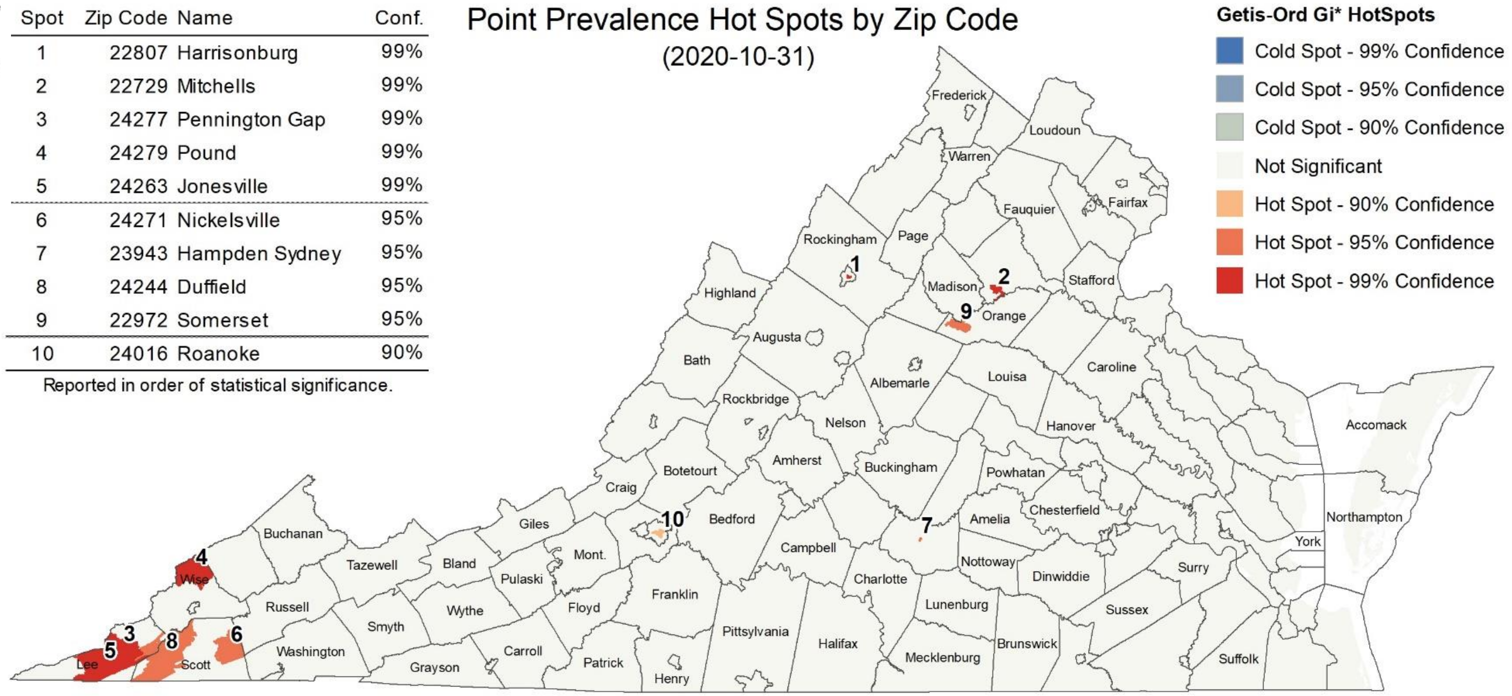
Hot Spot Significance	# of Zips (last week)
99%	5 (11)
95%	4 (3)
90%	1 (3)

Hotspots across commonwealth

- Concentrated in the Far Southwest
- Captures some very high prevalence rates in some zips

Spot	Zip Code	Name	Conf.
1	22807	Harrisonburg	99%
2	22729	Mitchells	99%
3	24277	Pennington Gap	99%
4	24279	Pound	99%
5	24263	Jonesville	99%
6	24271	Nickelsville	95%
7	23943	Hampden Sydney	95%
8	24244	Duffield	95%
9	22972	Somerset	95%
10	24016	Roanoke	90%

Reported in order of statistical significance.



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Model Update – Adaptive Fitting

Adaptive Fitting Approach

Each county fit precisely, with recent trends used for future projection

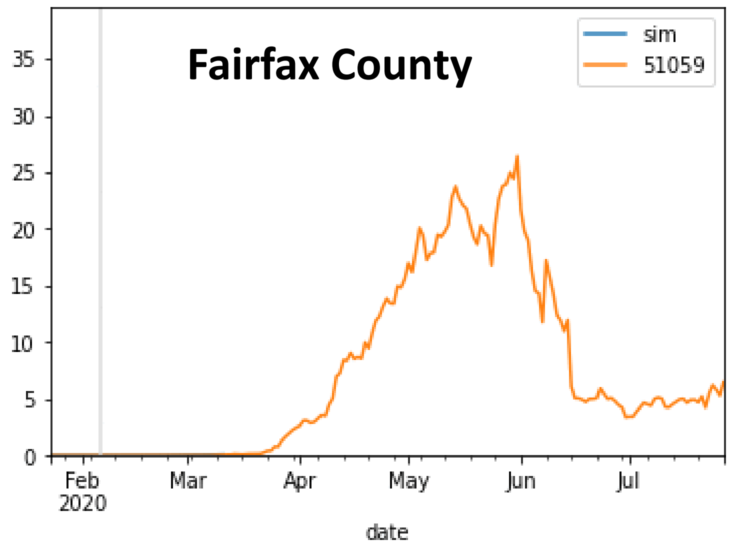
- Allows history to be precisely captured, and used to guide bounds on projections

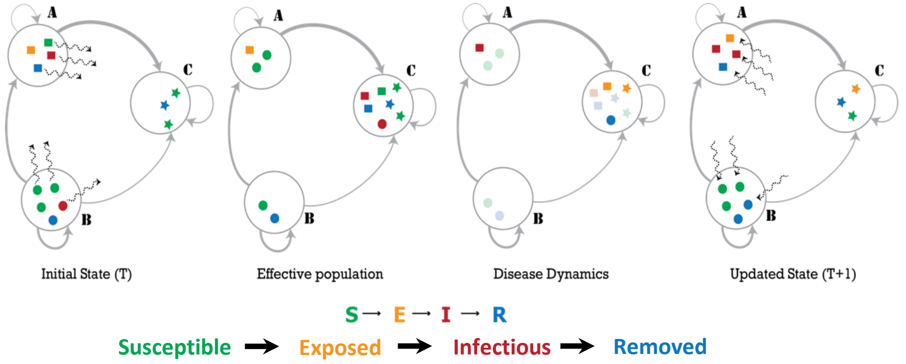
Model: An alternative use of the same meta-population model, PatchSim

  - Allows for future "what-if" Scenarios to be layered on top of calibrated model
  - Eliminates connectivity between patches, to allow calibration to capture the increasingly unsynchronized epidemic

External Seeding: Steady low-level importation

  - Widespread pandemic eliminates sensitivity to initial conditions
  - Uses steady 1 case per 10M population per day external seeding





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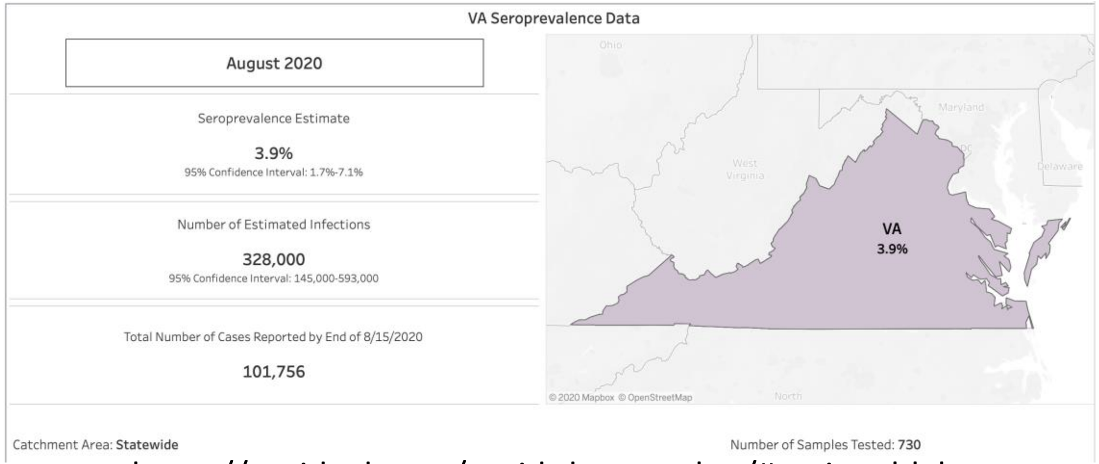
Seroprevalence updates to model design

Several seroprevalence studies provide better picture of how many actual infections have occurred

- Virginia Serology Study estimated 2.4% of Virginians estimated infected (as of Aug 15^{th})
- CDC Nationwide Commercial Laboratory Seroprevalence Survey estimated 3.9% [1.7% – 7.1%] seroprevalence as of Aug 15^{th}



https://covid.cdc.gov/covid-data-tracker/#national-lab

Virginia Coronavirus Serology Project
Interim findings by region and statewide - July 22, 2020

Region	Number of participants	Number antibody positive	Crude prevalence per 100 participants	Weighted prevalence* per 100 population	Weighted prevalence* (95% CI)
Central	400	8	2.0	3.0	(0.5, 5.5)
East	707	9	1.3	1.5	(-0.2, 3.2)
Northern	819	36	4.4	4.2	(2.5, 5.9)
Northwest	756	11	1.5	0.9	(0.2, 1.6)
Southwest	431	3	0.7	1.0	(-0.2, 2.1)
Virginia	3,113	67	2.2	2.4	(1.6, 3.1)

* Weighted prevalence is reweighted by region, age, sex, race, ethnicity, and insurance status to match census population.

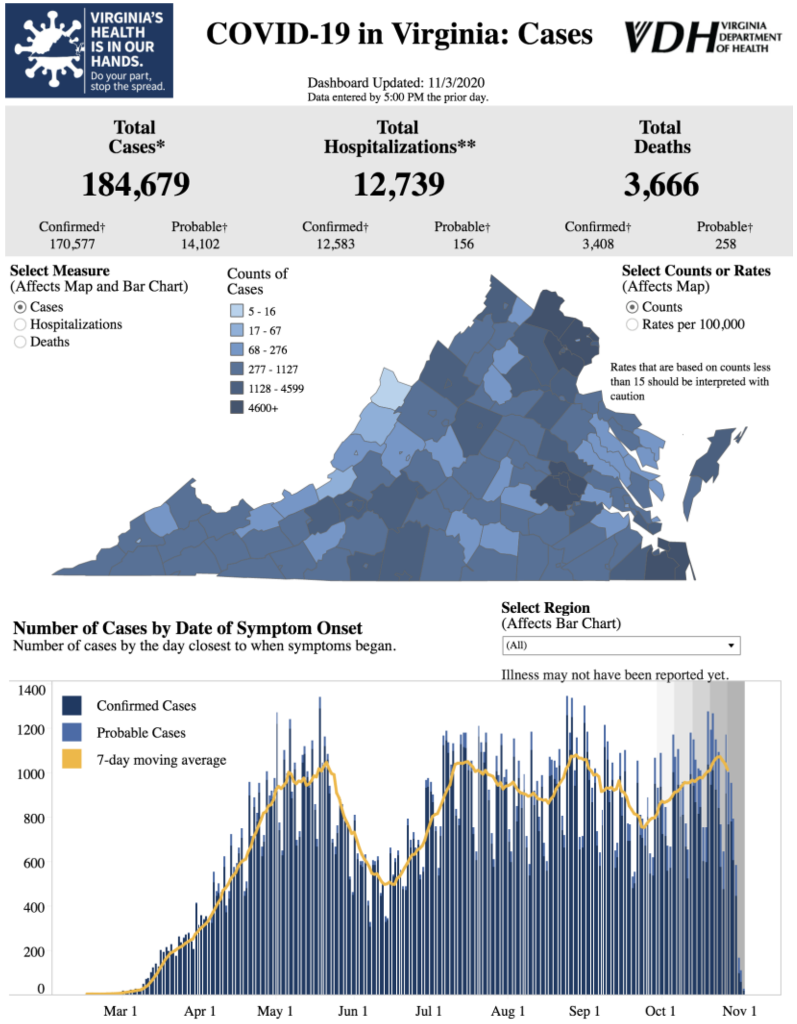
https://www.vdh.virginia.gov/content/uploads/sites/8/2020/08/VDH-Serology-Projects-Update-8-13-2020.pdf

These findings are equivalent to an ascertainment ratio of ~3x, with bounds of (1x to 7x)

- Thus for 3x there are 3 total infections in the population for every confirmed case
- Uncertainty design has been shifted to these bounds (previously higher ascertainments as was consistent earlier in the pandemic were being used)

Calibration Approach

- **Data:**
  - County level case counts by date of onset (from VDH)
  - Confirmed cases for model fitting
- **Calibration:** fit model to observed data
  - Tune transmissibility across ranges of:
    - Duration of incubation (5-9 days), infectiousness (3-7 days)
    - Undocumented case rate (1x to 7x) guided by seroprevalence studies
    - Detection delay: exposure to confirmation (4-12 days)
  - Approach captures uncertainty, but allows model to precisely track the full trajectory of the outbreak
- **Project:** future cases and outcomes using the most recent parameters with constraints learned from the history of the fit parameters
  - Mean trend from last 7 days used, adjusted by variances in the previous 3 weeks
  - 1 week interpolation to smooth transitions in rapidly changing trajectories
  - Particles with high error or variance filtered out



Accessed 2:00pm November 3, 2020
https://www.vdh.virginia.gov/coronavirus/

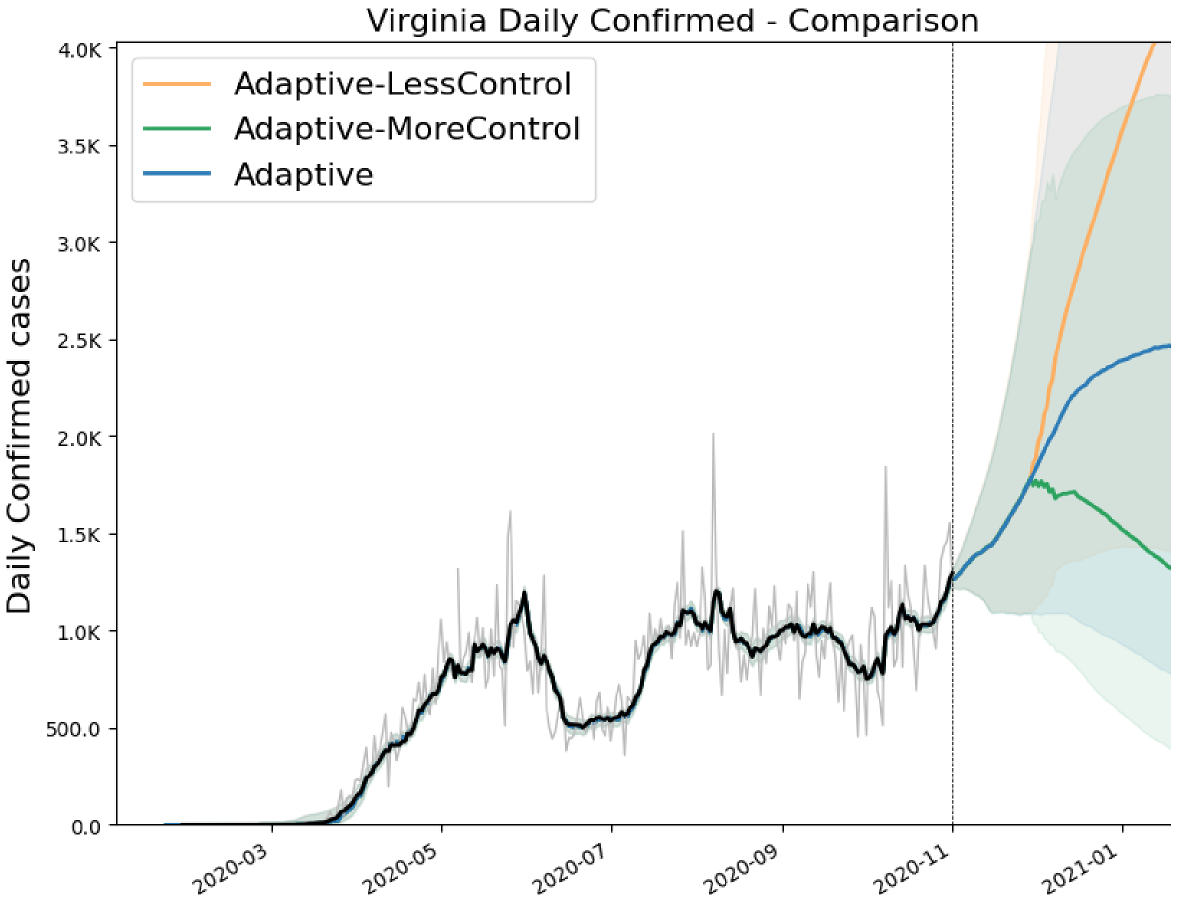
Scenarios – Seasonal Effects

- Societal changes in the past month have led to an increase in transmission rates, these could continue to drive transmission
  - Seasonal impact of weather patterns
  - More interactions at places of learning
  - Travel related to holidays and traditional large family gatherings
  - Fatigue with infection control practices
- Population's behaviors determine the level of control of transmission we can achieve
- Three scenarios capture possible trajectories starting Nov 26th, 2020
  - Adaptive: No change from base projection
  - Adaptive-MoreControl: 15% decrease in transmission starting Nov 26th, 2020
  - Adaptive-LessControl: 15% increase in transmission starting Nov 26th, 2020

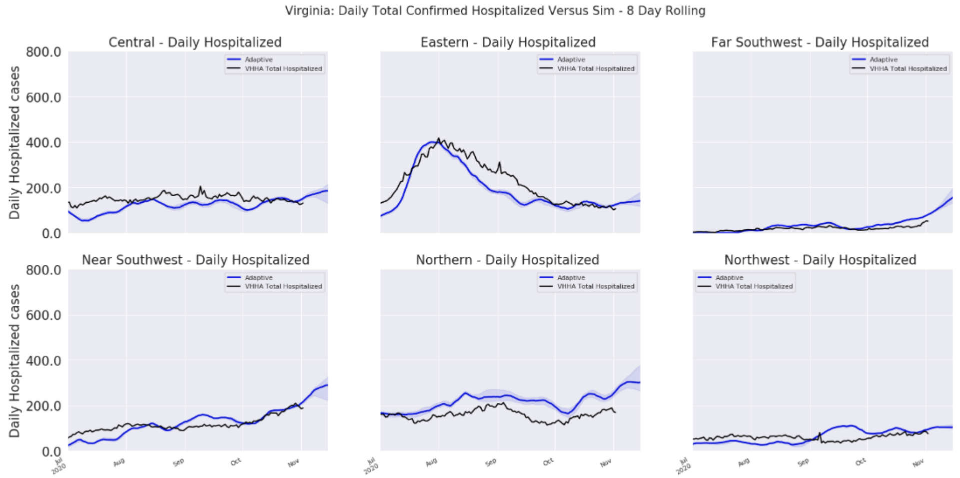
Model Results

Outcome Projections

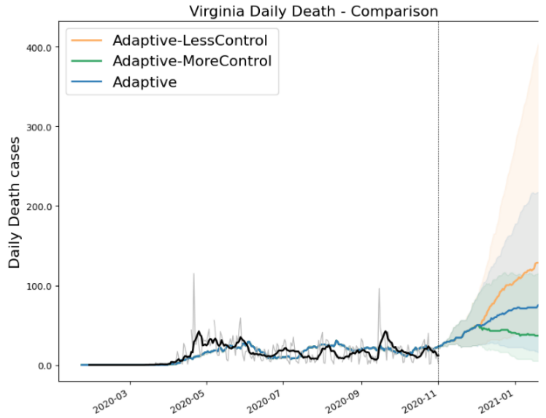
Confirmed cases



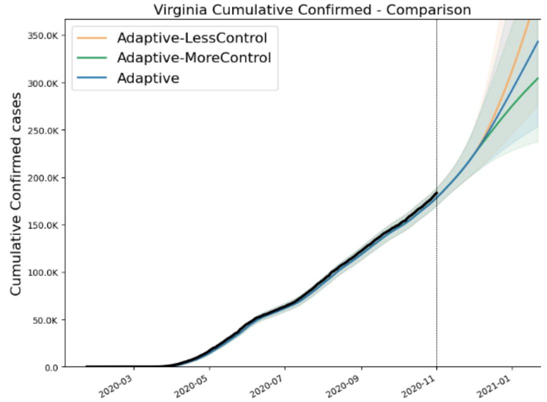
Estimated Hospital Occupancy



Daily Deaths



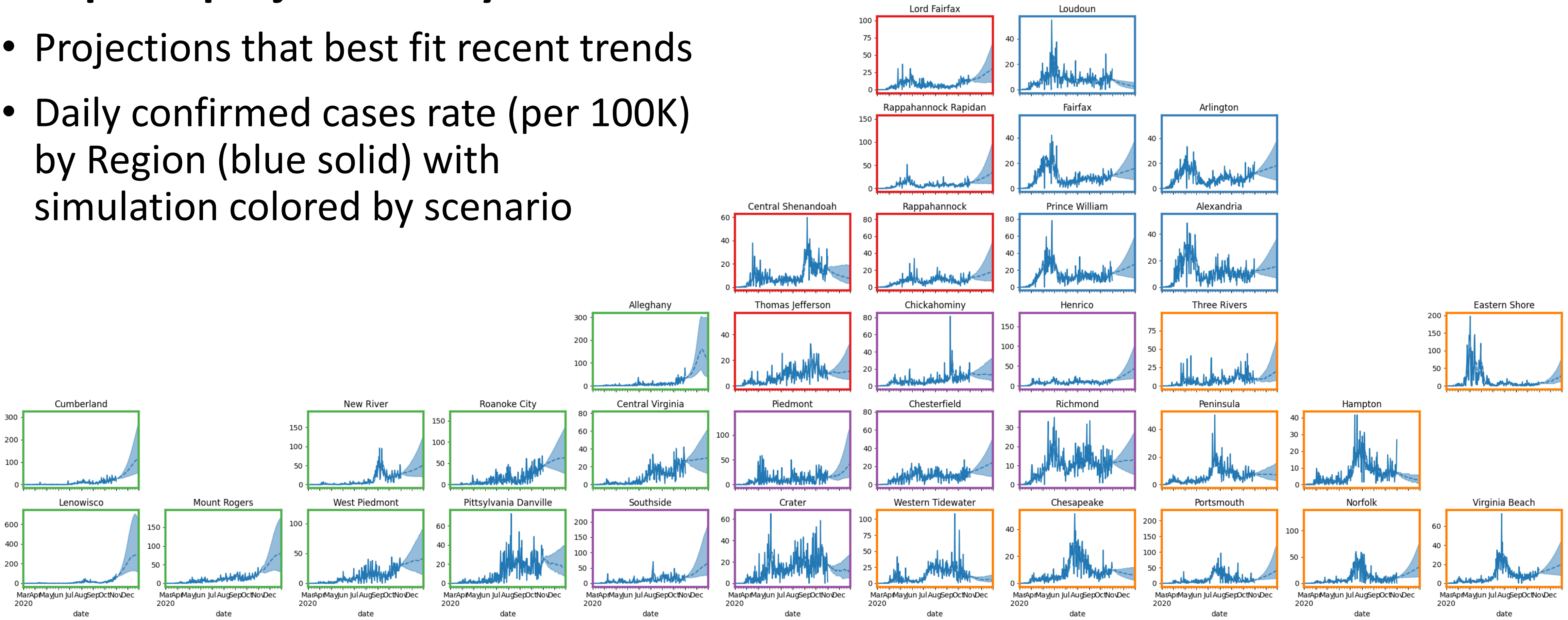
Cumulative Confirmed cases



District Level Projections: Adaptive

Adaptive projections by District

- Projections that best fit recent trends
- Daily confirmed cases rate (per 100K) by Region (blue solid) with simulation colored by scenario



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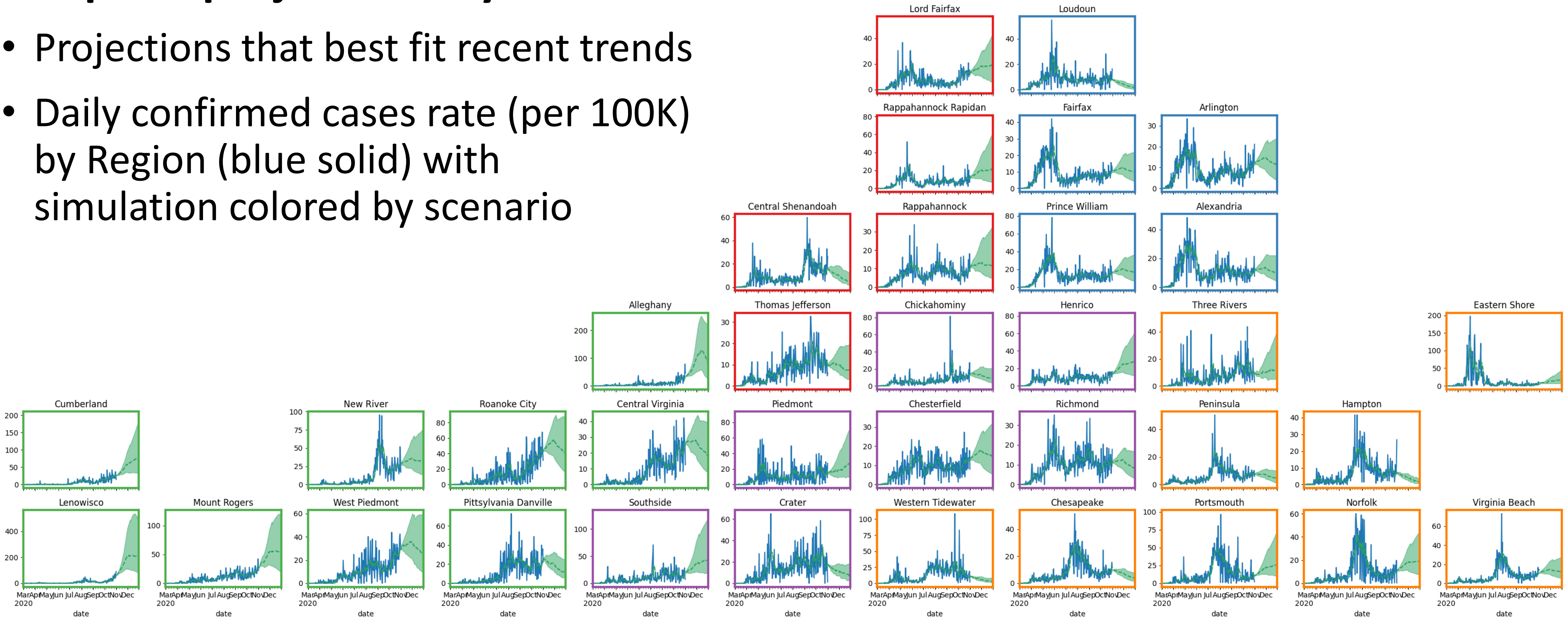
District Level Projections: Adaptive-MoreControl

Adaptive projections by District

- Projections that best fit recent trends
- Daily confirmed cases rate (per 100K) by Region (blue solid) with simulation colored by scenario



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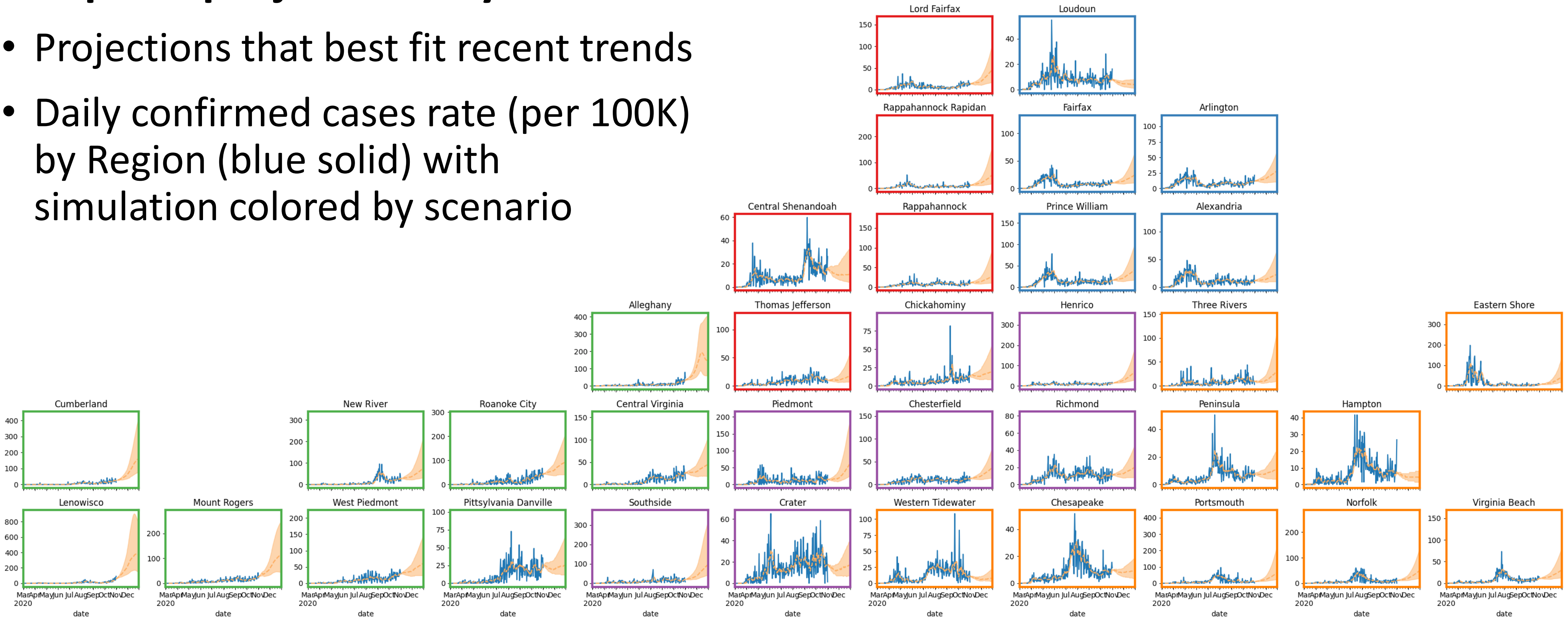
District Level Projections: Adaptive-LessControl

Adaptive projections by District

- Projections that best fit recent trends
- Daily confirmed cases rate (per 100K) by Region (blue solid) with simulation colored by scenario



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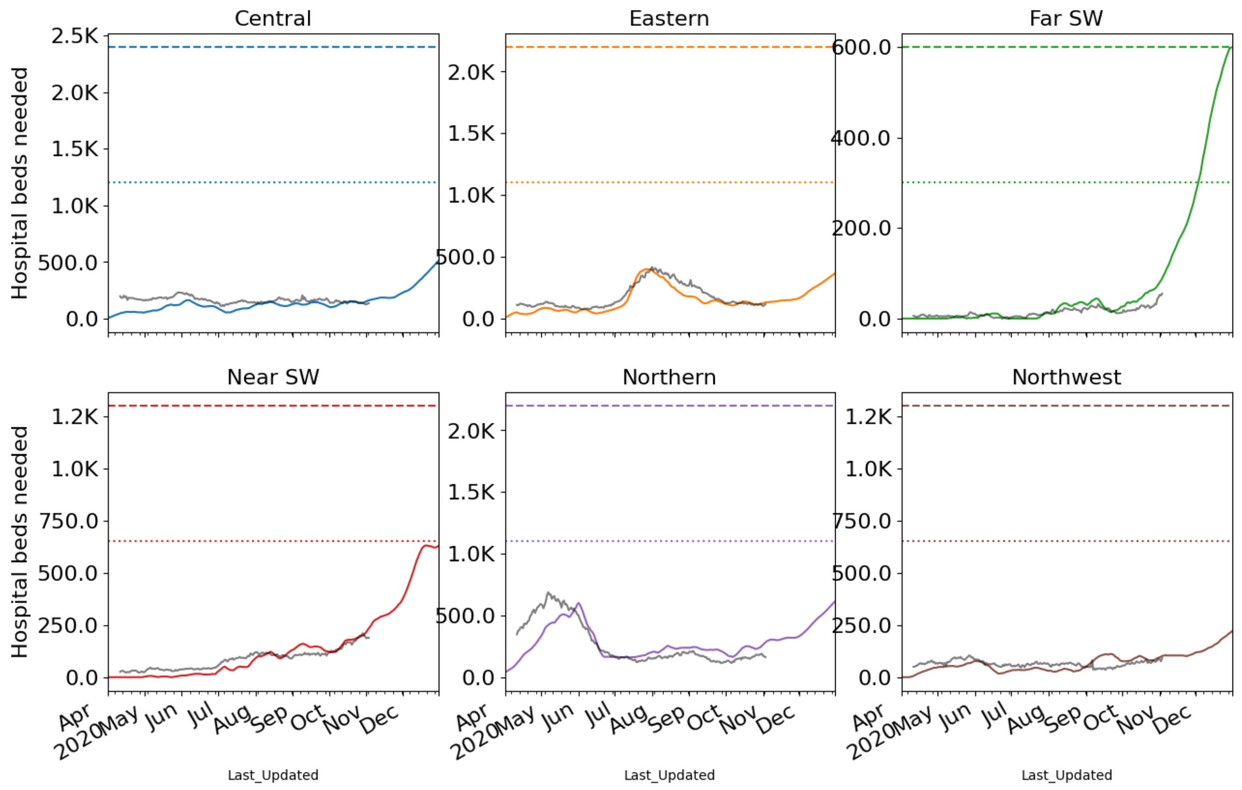
Hospital Demand and Bed Capacity by Region

Capacities by Region – Adaptive-LessControl

COVID-19 capacity ranges from 80% (dots) to 120% (dash) of total beds



Week Ending	Adaptive	Adaptive-LessControl
10/25/20	7,206	7,206
11/1/20	8,152	8,152
11/8/20	9,232	9,230
11/15/20	9,878	9,881
11/22/20	10,663	10,673
11/29/20	11,843	11,846
12/06/20	13,260	14,249
12/13/20	14,671	17,603
12/20/20	15,711	20,230
12/27/20	16,287	22,486
1/3/20	16,672	24,662
1/10/20	16,962	26,701

If Adaptive-LessControl scenario persists:

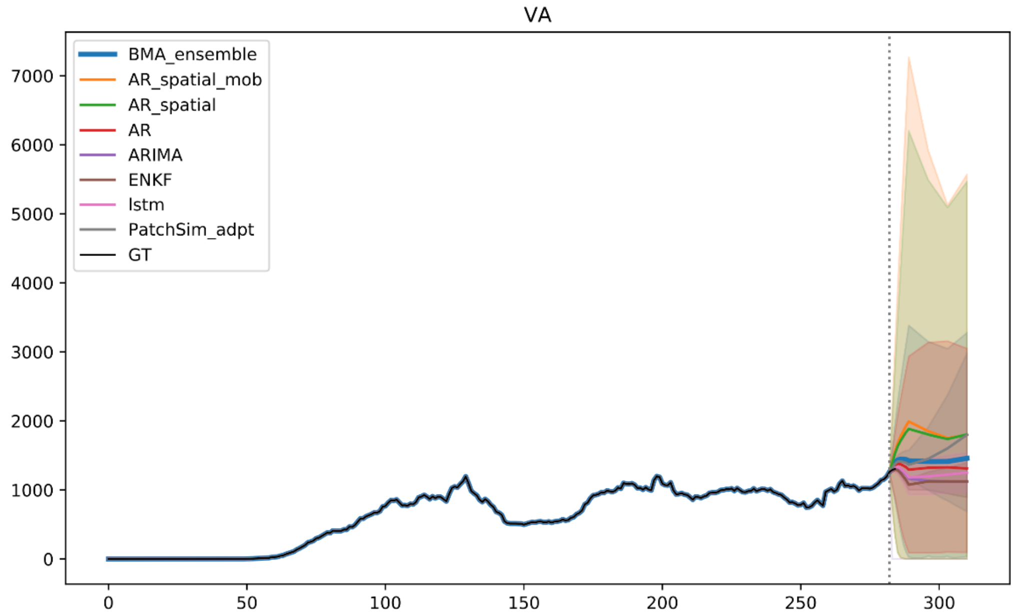
- Far Southwest may begin to exceed capacity in early December
- Near Southwest trends toward capacity as well by January

* Assumes average length of stay of 8 days

Additional Projection Methods under development

An ensemble methodology that combines the Adaptive Fitting and other machine learning and statistical models has been developed to facilitate use of other data (weather, mobility, etc.)

- **Models**: Adaptive Fitting, ARIMA, LSTM, AR, spatially driven AR, Kalman Filters (ENKF)
- Ensemble will be folded into these projections after further training and evaluation



Key Takeaways

Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

- **Virginia has had significant steady growth which is shared across the commonwealth.**
- VA weekly incidence (14.8/100K) is up though outpaced by the national average (34/100K).
- Projections are mostly up, showing potential for strain on health care system in some regions as early as December.
- Recent updates:
  - Planning Scenarios adjusted, as Adaptive Fitting tracks recent surge, to represent population's ability to exert further control on transmission following Thanksgiving holidays, Nov 26th.
  - Case ascertainment parameters now bounded by updated seroprevalence data.
- The situation is changing rapidly. Models will be updated regularly.

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Venkatramanan, S., et al. "Optimizing spatial allocation of seasonal influenza vaccine under temporal constraints." *PLoS computational biology* 15.9 (2019): e1007111.

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Biocomplexity Institute. COVID-19 Surveillance Dashboard. https://nssac.bii.virginia.edu/covid-19/dashboard/

Google. COVID-19 community mobility reports. https://www.google.com/covid19/mobility/

Biocomplexity page for data and other resources related to COVID-19: https://covid19.biocomplexity.virginia.edu/

Questions?

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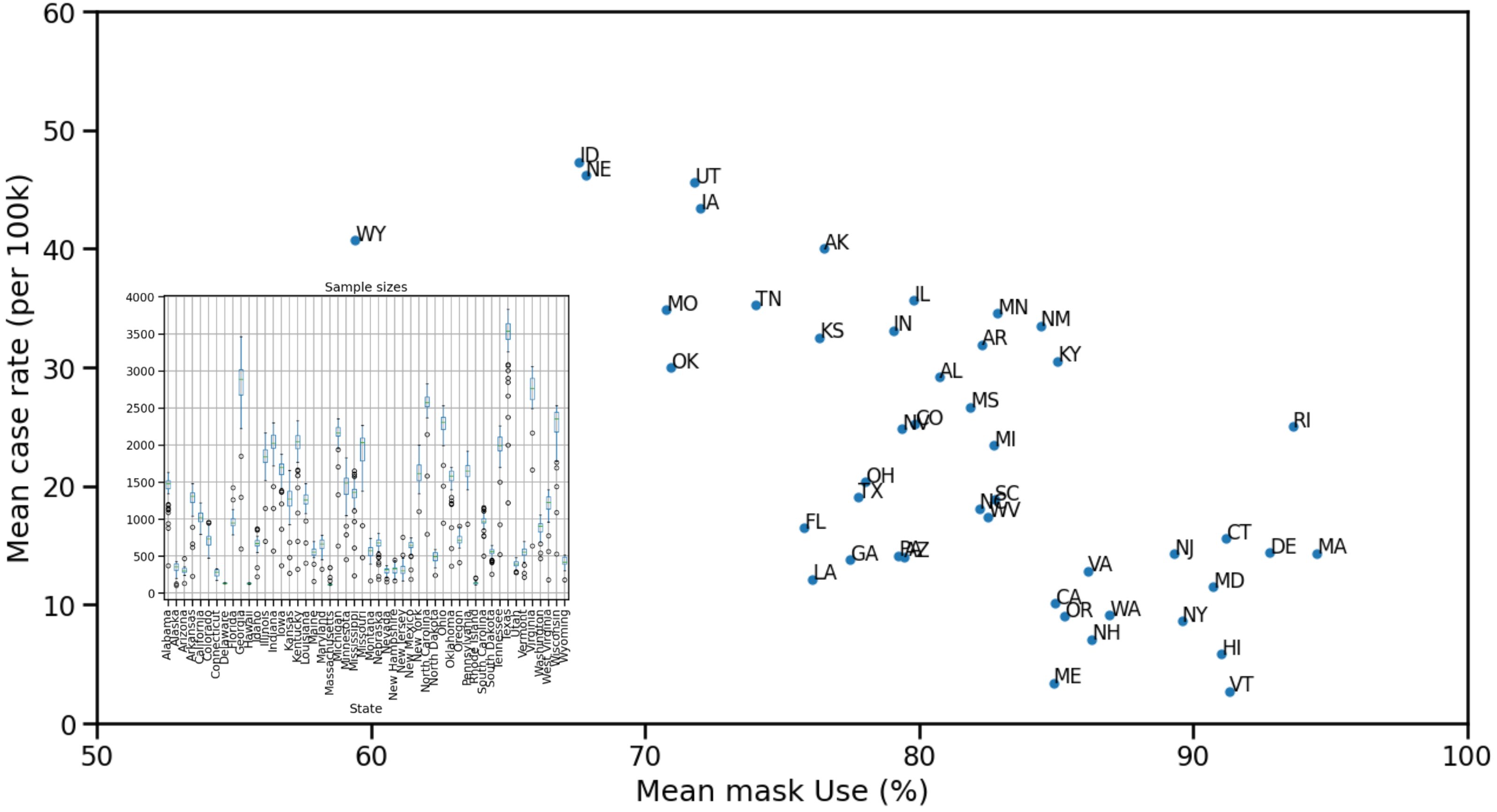
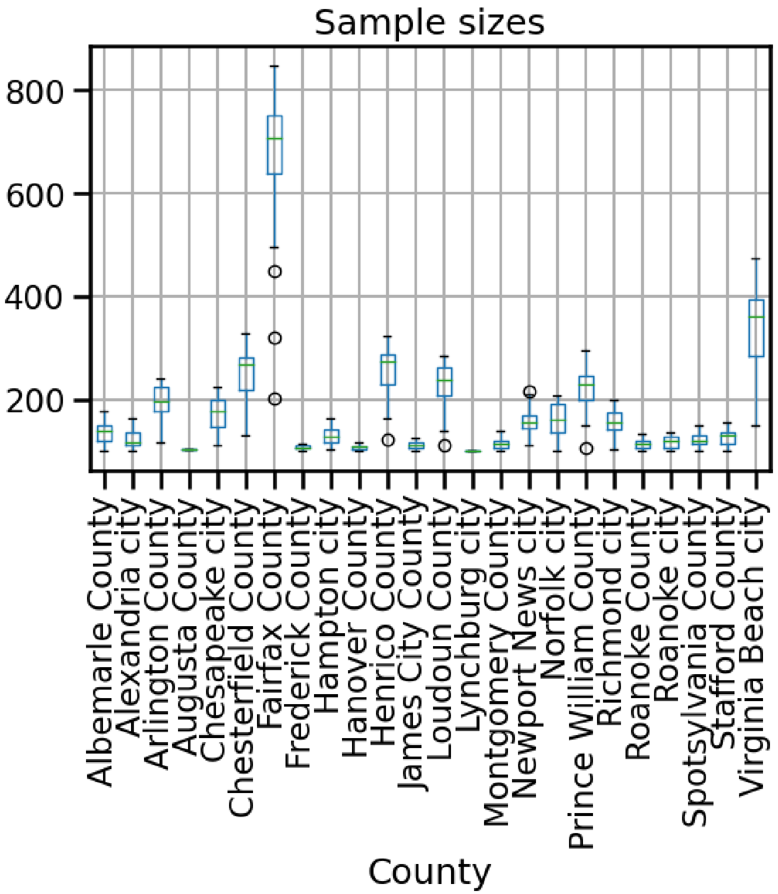
Supplemental Slides

Mask usage sample sizes





Test positivity across VA counties

- CMS weekly summary (used for guiding nursing homes testing protocol)
- Data: COVID-19 Electronic Lab Reporting (CELR); HHS Unified Testing Dataset;
- County level testing counts and test positivity rates for RT-PCR tests.
  - Green: Test positivity <5.0% or with <20 tests in past 14 days
  - Yellow: Test positivity 5.0%-10.0% or with <500 tests and <2000 tests/100k and >10% positivity over 14 days
  - Red: >10.0% and not meeting the criteria for "Green" or "Yellow"

County	Sep-30	Oct-07	Oct-14	Oct-21
Amherst County	Yellow	Red	Red	Red
Bedford County	Yellow	Red	Red	Red
Bristol City	Yellow	Yellow	Red	Red
Campbell County	Yellow	Red	Red	Red
Charlotte County	Red	Red	Red	Red
Craig County	Yellow	Yellow	Red	Red
Franklin City	Yellow	Yellow	Red	Red
Franklin County	Red	Red	Red	Red
Galax City	Red	Yellow	Yellow	Red
Greensville County	Red	Red	Red	Red
Henry County	Red	Yellow	Red	Red
Lee County	Yellow	Yellow	Red	Red
Manassas City	Yellow	Red	Red	Red
Martinsville City	Yellow	Red	Red	Red
Prince Edward County	Yellow	Yellow	Yellow	Red
Prince George County	Red	Red	Red	Red
Radford City	Green	Green	Yellow	Red
Roanoke County	Yellow	Yellow	Red	Red
Scott County	Yellow	Yellow	Red	Red
Southampton County	Red	Red	Red	Red
Tazewell County	Yellow	Yellow	Yellow	Red
Washington County	Red	Red	Red	Red
Wise County	Yellow	Red	Yellow	Red
Wythe County	Yellow	Yellow	Yellow	Red

Red on Oct 21 (latest)

County	Sep-30	Oct-07	Oct-14	Oct-21
Charlotte County	Red	Red	Red	Red
Franklin County	Red	Red	Red	Red
Galax City	Red	Yellow	Yellow	Red
Grayson County	Red	Yellow	Yellow	Yellow
Greensville County	Red	Red	Red	Red
Harrisonburg City	Red	Yellow	Yellow	Yellow
Henry County	Red	Yellow	Red	Red
Mathews County	Red	Red	Yellow	Yellow
Pittsylvania County	Red	Red	Red	Yellow
Prince George County	Red	Red	Red	Red
Rockingham County	Red	Red	Red	Yellow
Southampton County	Red	Red	Red	Red
Surry County	Red	Red	Yellow	Yellow
Sussex County	Red	Yellow	Green	Green
Washington County	Red	Red	Red	Red

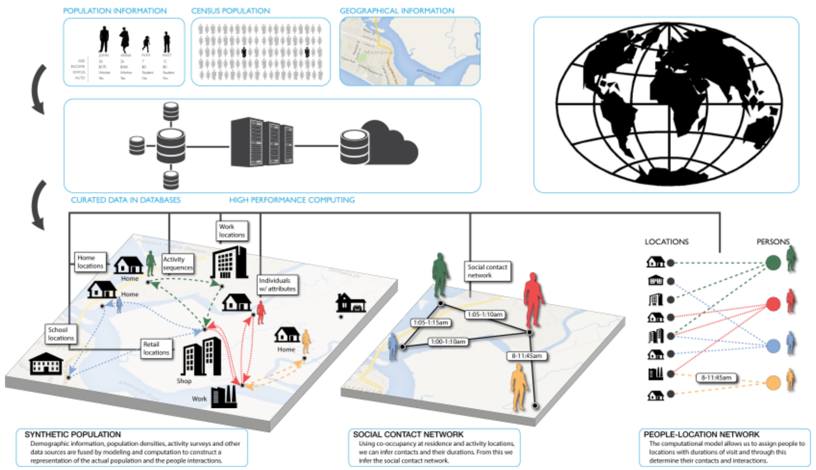
Red on Sep 30 (4-week back)

https://data.cms.gov/stories/s/q5r5-gjyu

Agent-based Model (ABM)

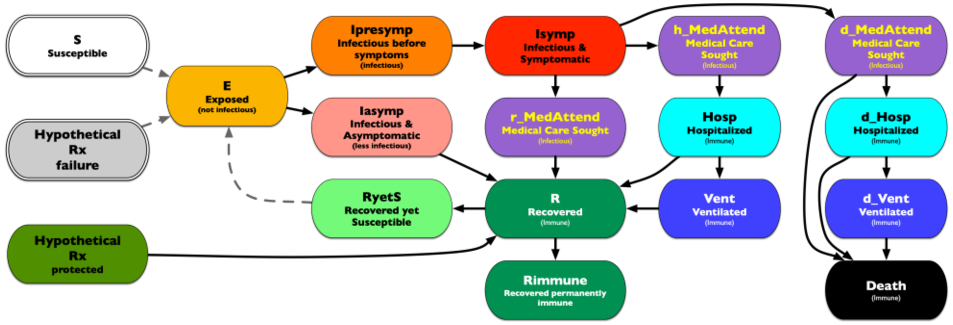
EpiHiper: Distributed network-based stochastic disease transmission simulations

- Assess the impact on transmission under different conditions
- Assess the impacts of contact tracing



Synthetic Population

- Census derived age and household structure
- Time-Use survey driven activities at appropriate locations



Detailed Disease Course of COVID-19

- Literature based probabilities of outcomes with appropriate delays
- Varying levels of infectiousness
- Hypothetical treatments for future developments

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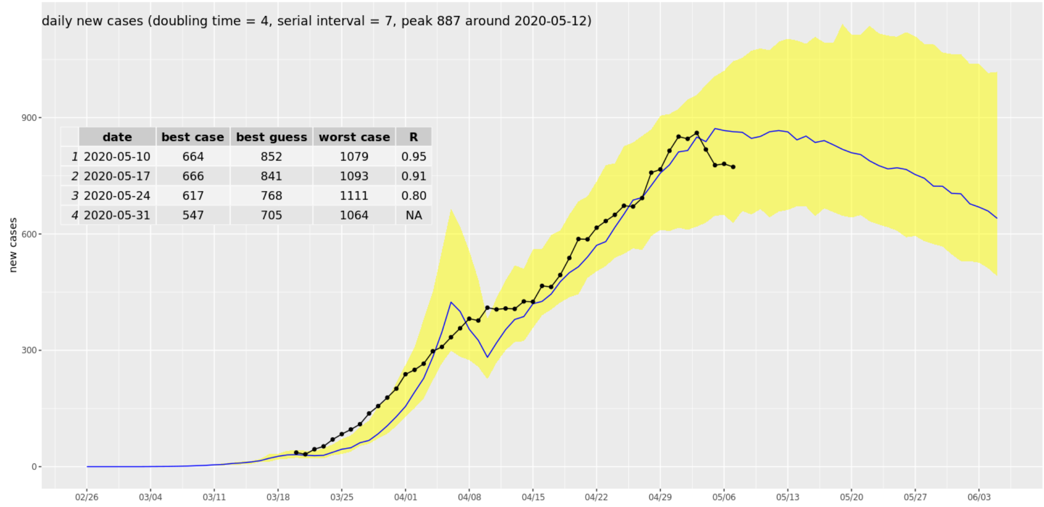
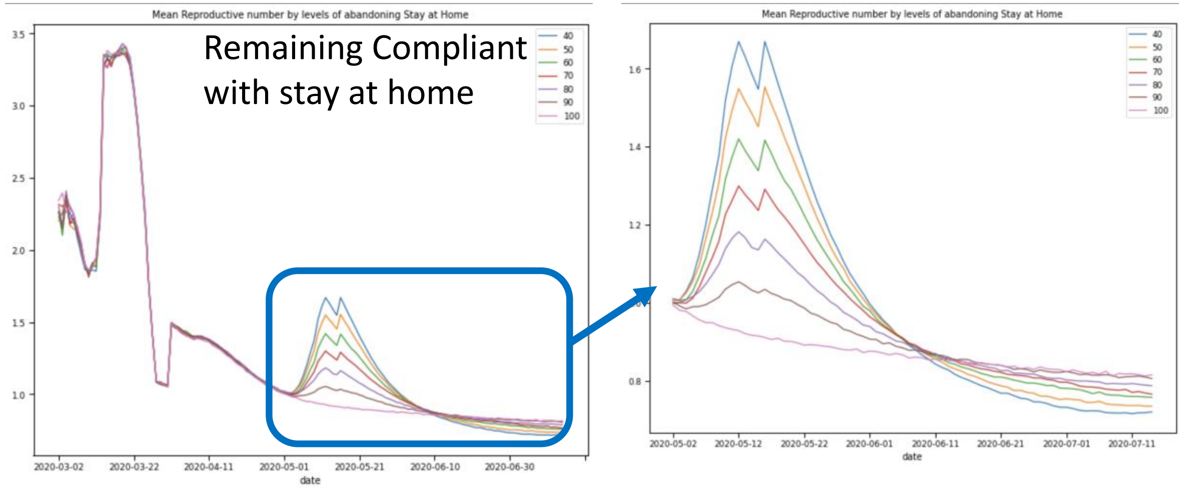
ABM Social Distancing Rebound Study Design

Study of ”Stay Home” policy adherence

- Calibration to current state in epidemic
- Implement “release” of different proportions of people from ”staying at home”



	date	best case	best guess	worst case	R
1	2020-05-10	664	852	1079	0.95
2	2020-05-17	666	841	1093	0.91
3	2020-05-24	617	768	1111	0.80
4	2020-05-31	547	705	1064	NA



Calibration to Current State

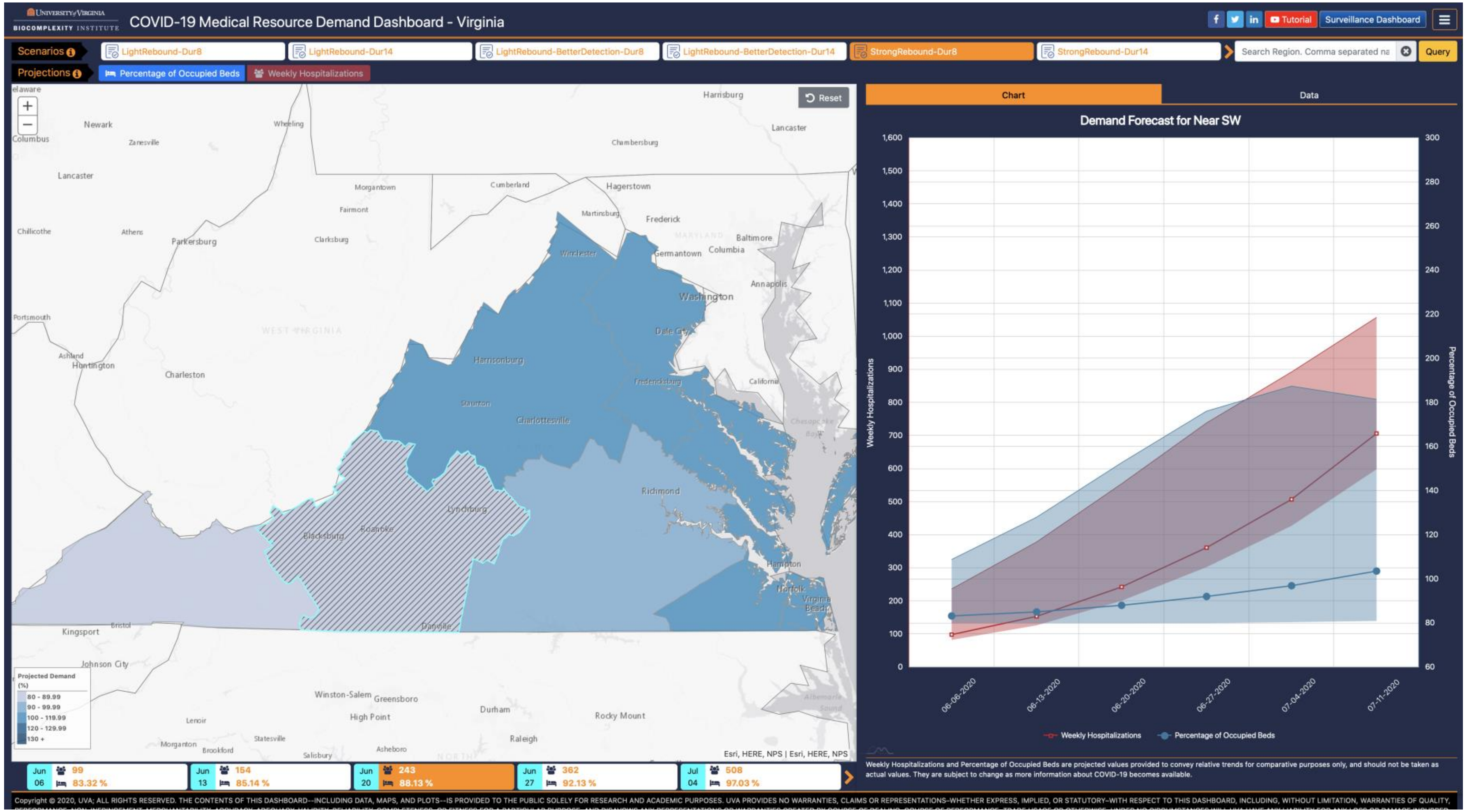
- Adjust transmission and adherence to current policies to current observations
- For Virginia, with same seeding approach as PatchSim

Impacts on Reproductive number with release

- After release, spike in transmission driven by additional interactions at work, retail, and other
- At 25% release (70-80% remain compliant)
- Translates to 15% increase in transmission, which represents a 1/6th return to pre-pandemic levels

Medical Resource Demand Dashboard

https://nssac.bii.virginia.edu/covid-19/vmrddash/



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