Network Systems
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Biocomplexity Institute
& Initiative

University of Virginia

Estimation of COVID-19 Impact in Virginia

January 6th , 2021

(data current to January 4th-5th)
Biocomplexity Institute Technical report: TR 2021-002

University *of* Virginia

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biocomplexity.virginia.edu

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 based on scenarios for next 4 months
  - 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

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Key Takeaways

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

- **Case rate growth in Virginia has fluctuated through the holidays and is up overall.**

- VA mean weekly incidence (52/100K) up (from 42) as national levels rebound (to 58/100K from 48/100K).

- Projections are mixed across commonwealth but generally up as well.

- Recent updates:
  - Preliminary estimates for vaccination impact
  - Planning scenarios shifted to early January (Jan 8)
  - Added a 3 week "Strong Control" control strategy to scenarios

- Behavioral changes can outpace impact of optimistic vaccine rollout and prevent significantly more cases by Spring.

- The situation is changing rapidly. Models will be updated regularly.

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Situation Assessment

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Case Rate (per 100k) by VDH District

Surging Rates continue

- Majority of districts have increasing rates

- Many districts experiencing highest rates of pandemic

- Some districts remain steady or decreasing
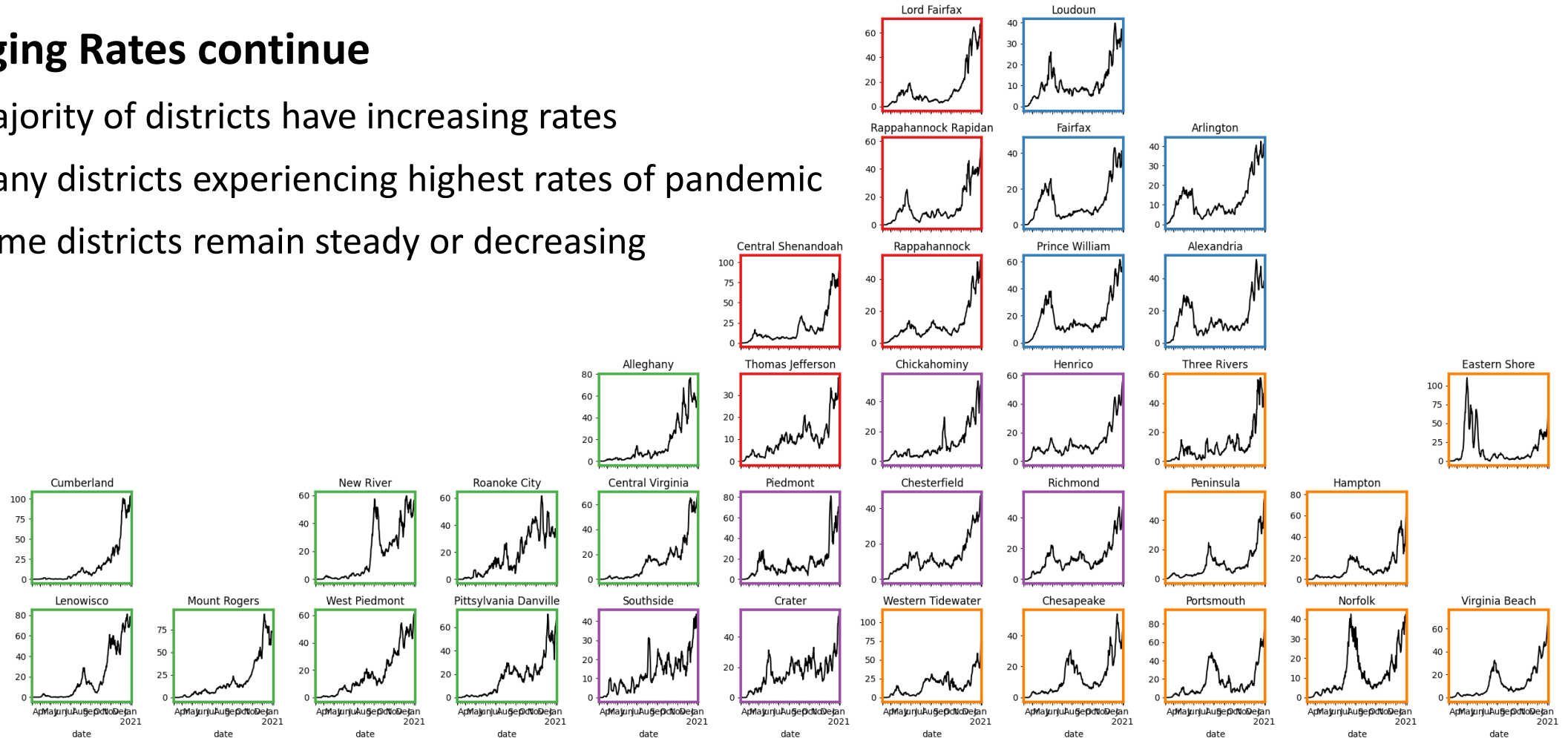
Test Positivity by VDH District

Weekly changes in test positivity by district

- Increasing levels in many districts throughout the commonwealth with many districts above 10% for several weeks

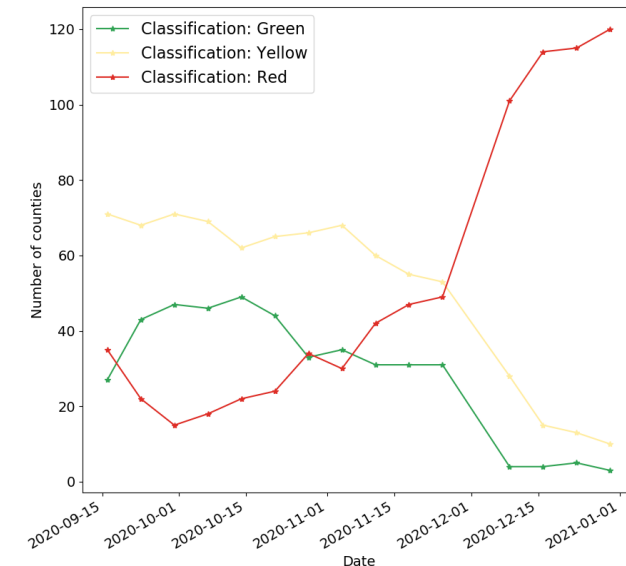- 120 counties reporting over 10% on Dec 30
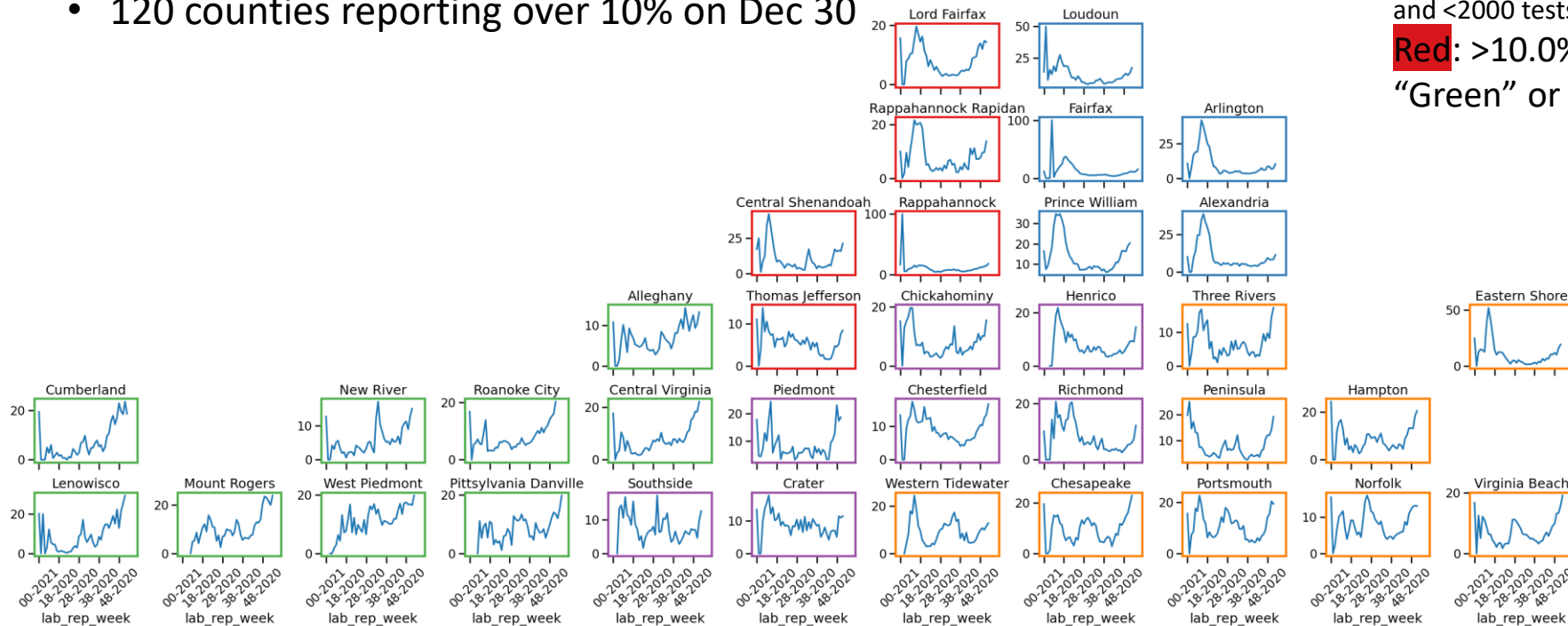
County level test positivity rates for RT-PCR tests.

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"

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

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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
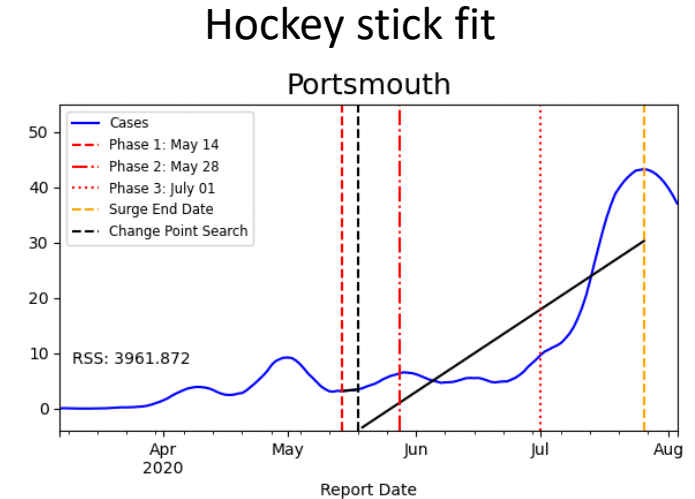
Trajectory	Description	Weekly Case Rate (per 100K) bounds	# Districts (prev week)
Declining	Sustained decreases following a recent peak	below -0.9	10 (12)
Plateau	Steady level with minimal trend up or down	above -0.9 and below 0.5	3 (4)
Slow Growth	Sustained growth not rapid enough to be considered a Surge	above 0.5 and below 2.5	13 (9)
In Surge	Currently experiencing sustained rapid and significant growth	2.5 or greater	9 (10)

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District Trajectories

Status	# Districts (prev week)
Declining	10 (12)
Plateau	3 (4)
Slow Growth	13 (9)
In Surge	9 (10)

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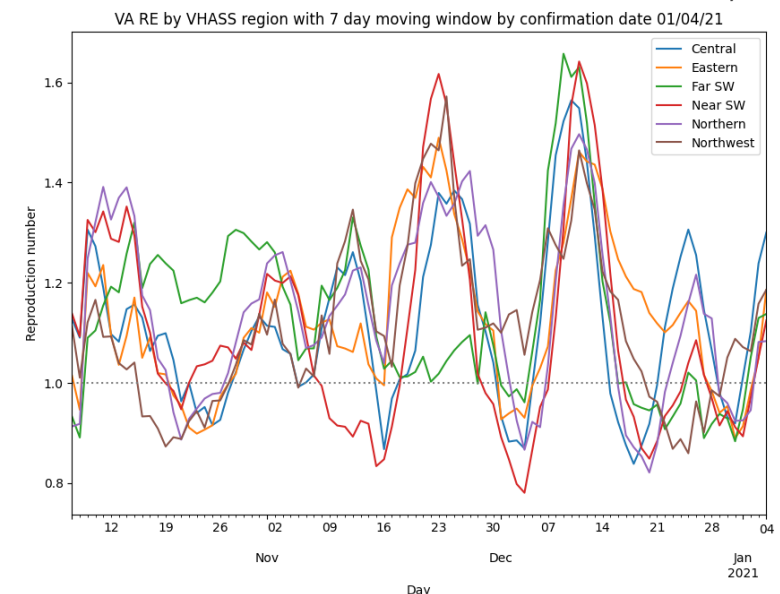Case Rate curve colored by Reproductive

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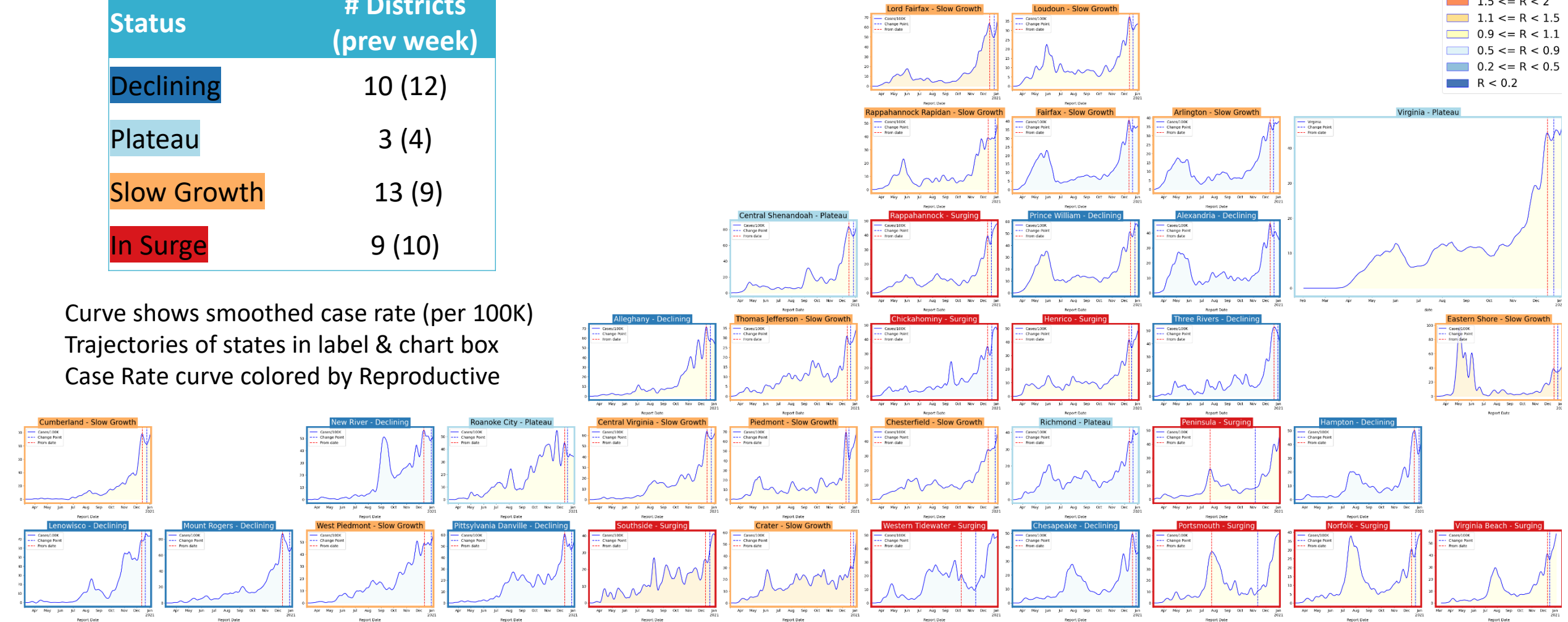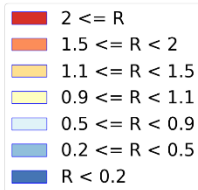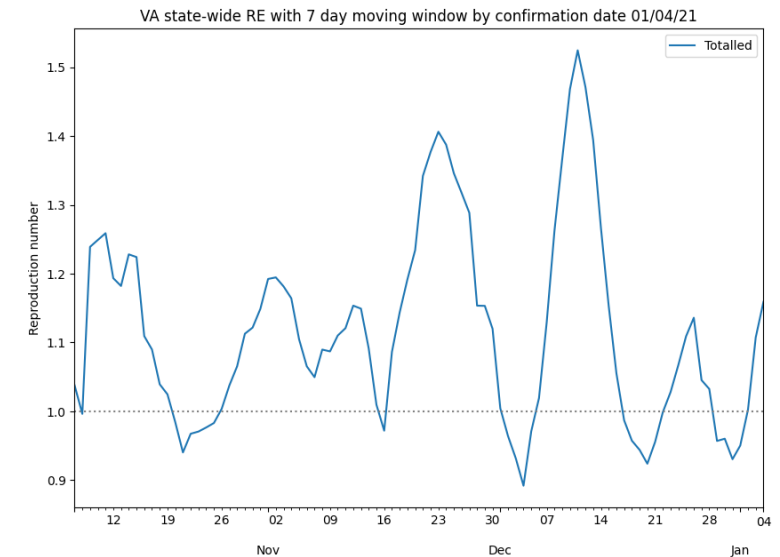
Estimating Daily Reproductive Number

Jan 4th Estimates

Region	Date Confirmed R_e	Date Confirmed Diff Last Week
State-wide	1.159	0.127
Central	1.300	0.235
Eastern	1.185	0.202
Far SW	1.137	0.220
Near SW	1.125	0.155
Northern	1.083	-0.045
Northwest	1.186	0.201

Methodology

- Wallinga-Teunis method (EpiEstim[1]) for cases by **confirmation date**

- Serial interval: 6 days (2 day std dev)

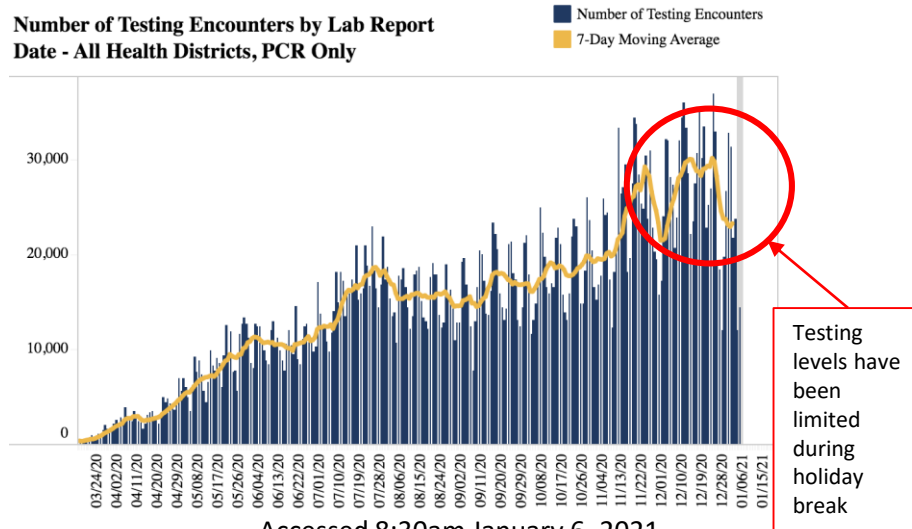- Using Confirmation date since due to increasingly unstable estimates from onset date due to backfill

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

VA state-wide RE with 7 day moving window by confirmation date 01/04/21

VA RE by VHASS region with 7 day moving window by confirmation date 01/04/21

Changes in Case Detection

Timeframe (weeks)	Mean days	% difference from overall mean
April (13-16)	7.8	44%
May (17-21)	5.7	6%
June (22-25)	5.9	9%
July (26-30)	6.2	15%
Aug (31-34)	4.9	-9%
Sept (35-38)	4.5	-16%
Oct (39-43)	4.5	-17%
Nov (44-47)	4.5	-18%
Dec (48-49)	4.0	-26%
Overall (13-49)	5.4	--

Test positivity vs. Onset to Diagnosis

Positivity continues to climb

Number of Testing Encounters by Lab Report Date - All Health Districts, PCR Only

Testing levels have been limited during holiday break

Accessed 8:30am January 6, 2021
https://www.vdh.virginia.gov/coronavirus/
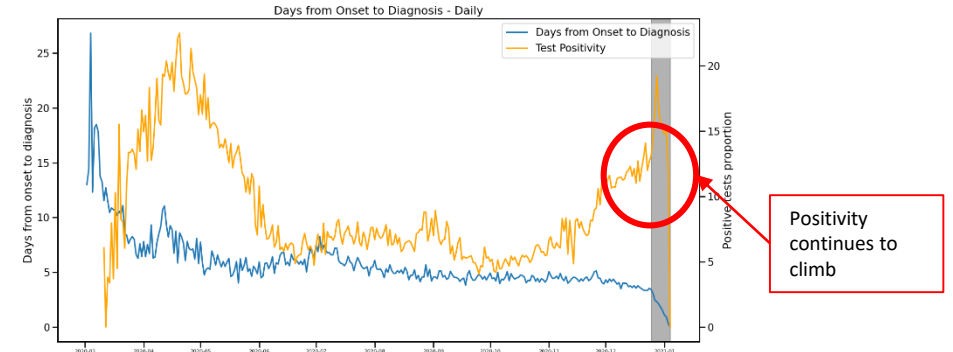
Days from Onset to Diagnosis and Test Positivity - Weekly

July 6.2 days

Aug 4.9 days

Sept 4.5 days

Oct 4.5 days

Nov 4.5 days

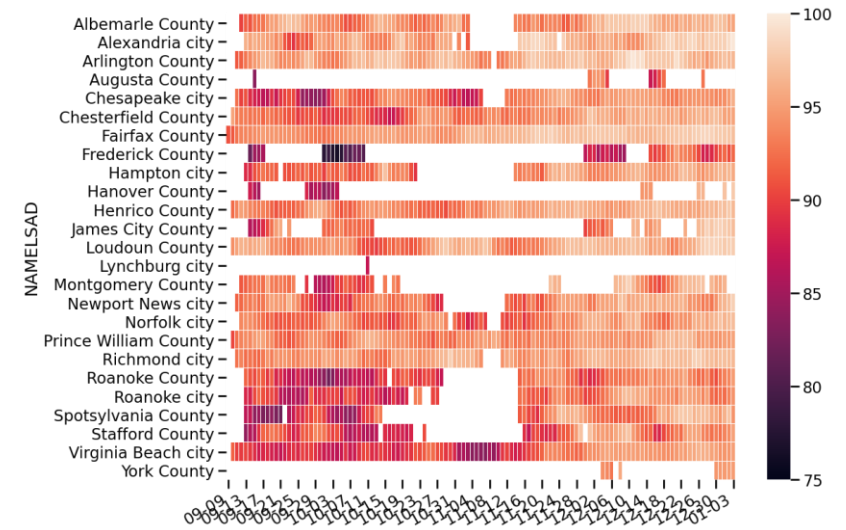Dec 4.0 days

Weeks (WW-YYYY)

7-Jan-21

11
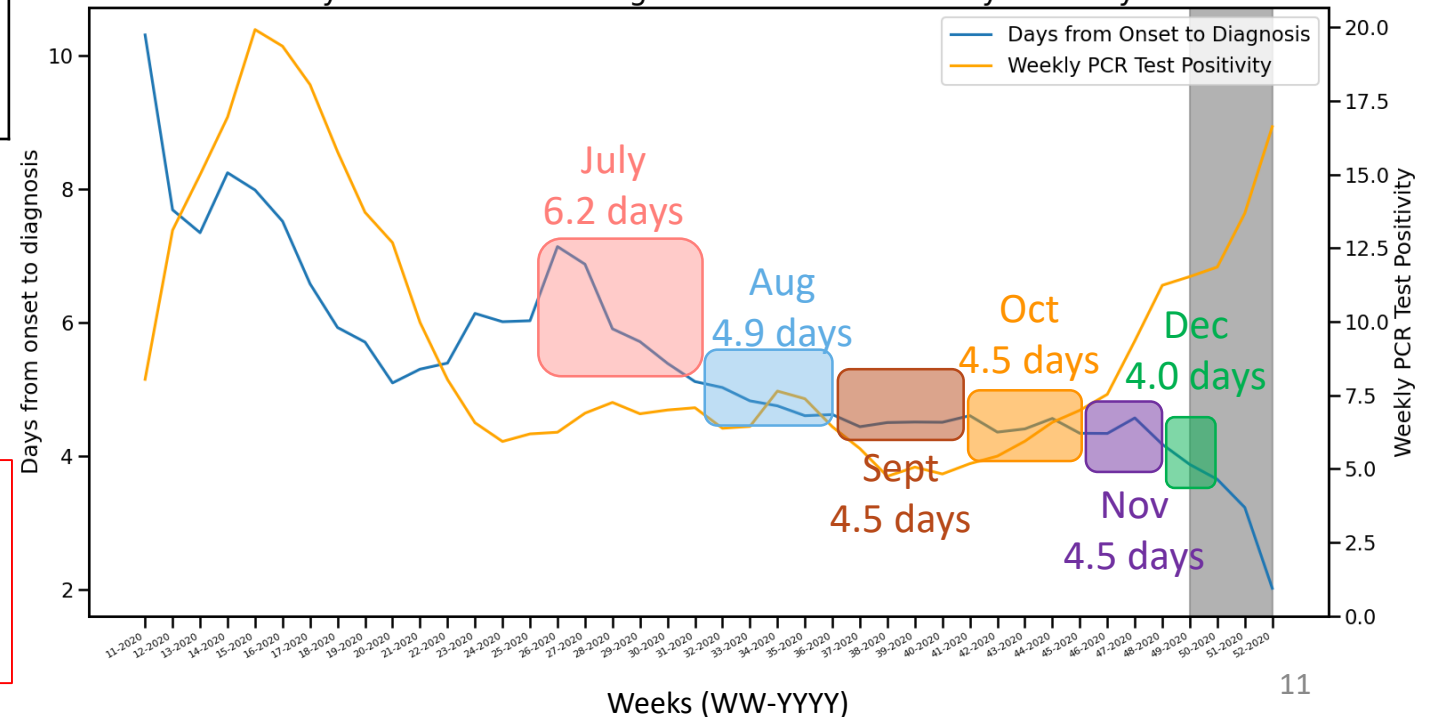
Mask usage in Virginia
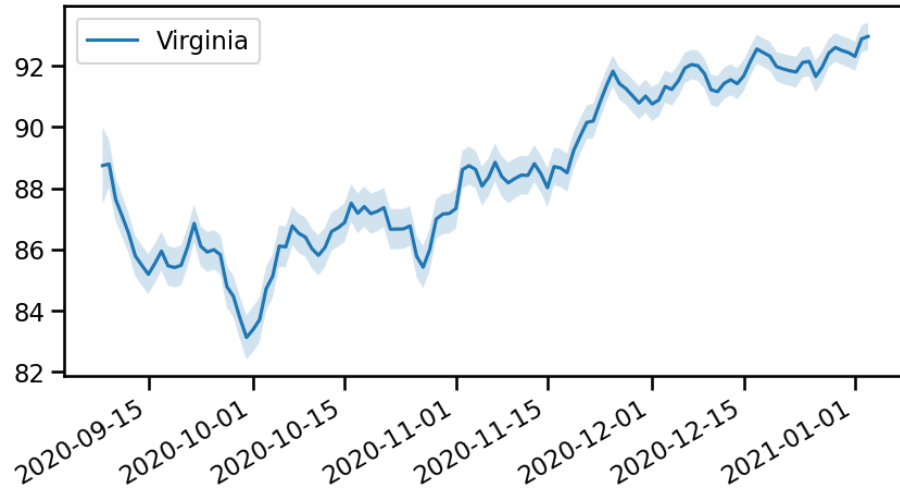
State level mask usage as reported via Facebook surveys over the past month shows ranges from 83% to 91%
- Relatively stable over time
- Limited variance across the commonwealth
- ~3000 daily responses from VA

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

Some county level fluctuations since beginning of Sept., though data quality may be affected by sample sizes.
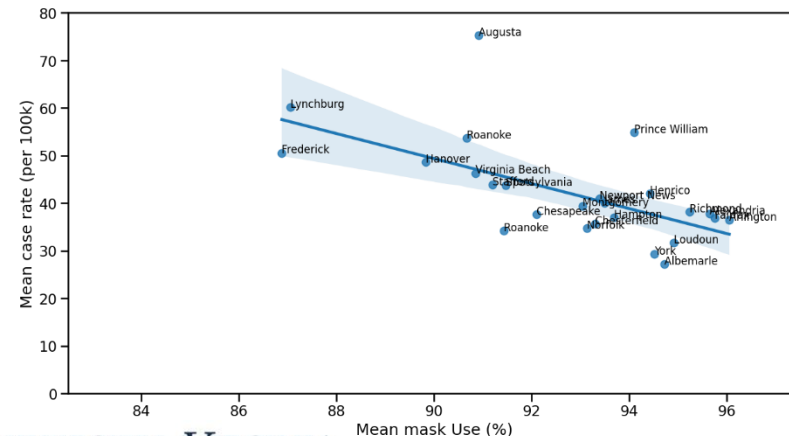
Correlations seen among VA counties between mask use and case rate are now stronger due to surging growth
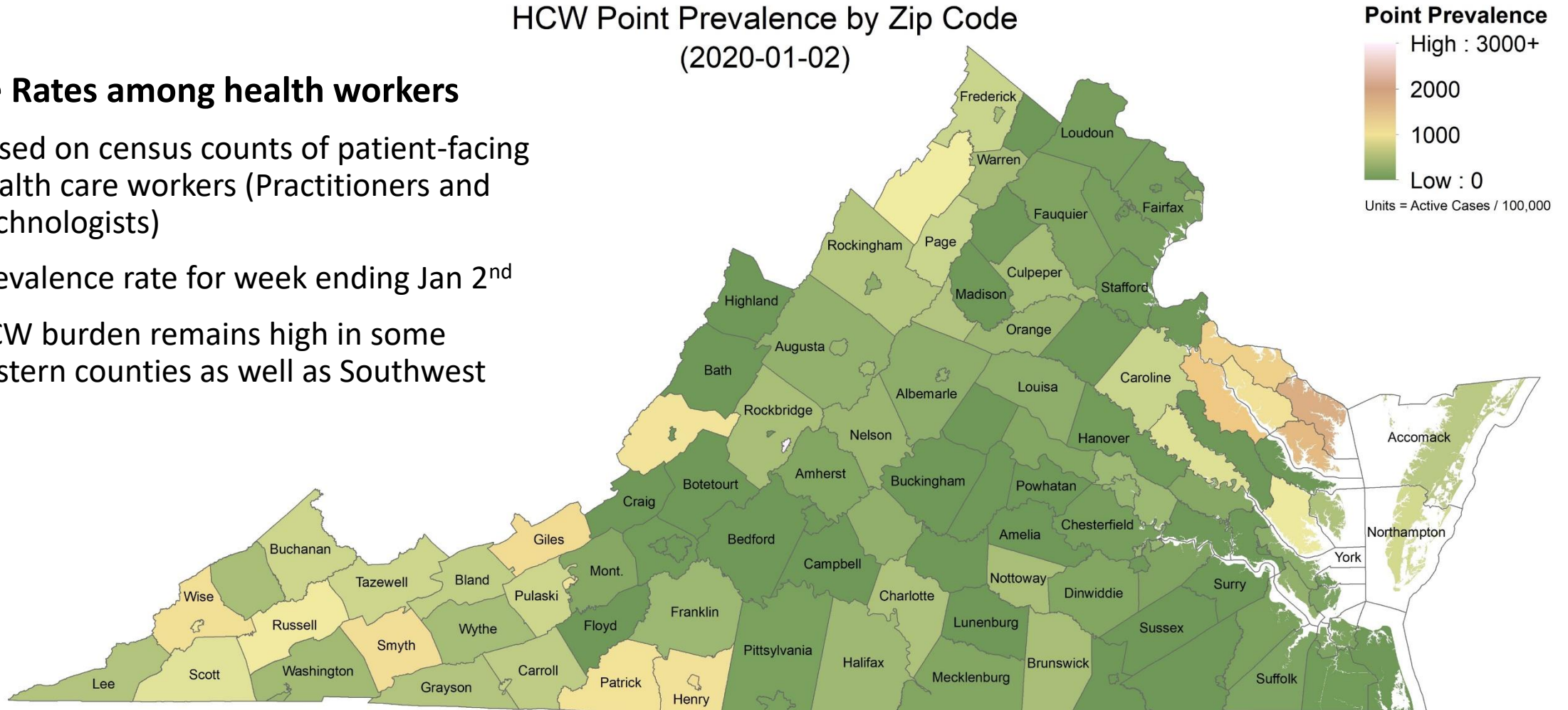
Slope: - 2.85; for every % we see a ~3/100K case rate difference

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Health Care Worker Prevalence (per 100K)

Case Rates among health workers

- Based on census counts of patient-facing health care workers (Practitioners and Technologists)

- Prevalence rate for week ending Jan 2nd

- HCW burden remains high in some Eastern counties as well as Southwest

HCW Point Prevalence by Zip Code
(2020-01-02)

Point Prevalence

High : 3000+

2000

1000

Low : 0

Units = Active Cases / 100,000

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Race and Ethnicity – Recent Rate Changes (per 100K)

Recent Changes in Race and Ethnicity Rates (per 100k)

- Two week change in population level rates

- Black, Latinx and 2 or more races populations have much higher changes in rates; disparity is more pronounced in some districts than others

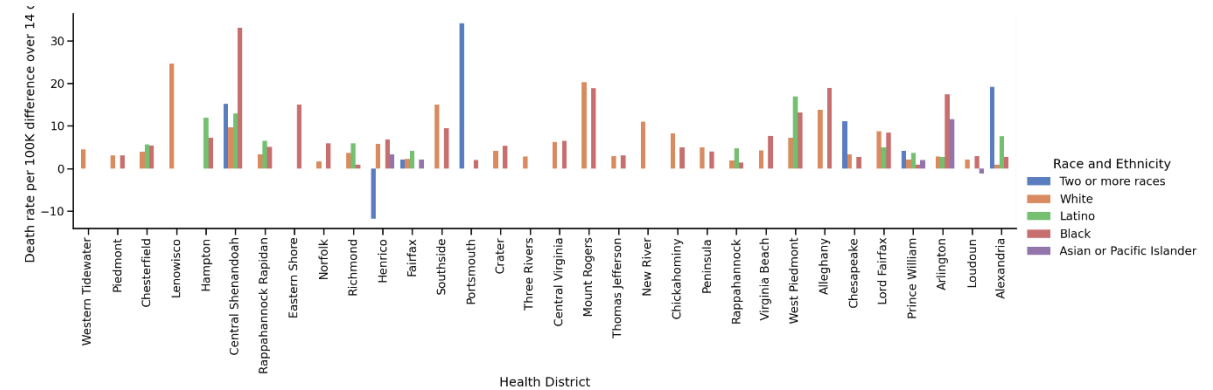- Based on 2019 census race-ethnicity data by county

Case Rate

Hospitalization Rate

Death Rate

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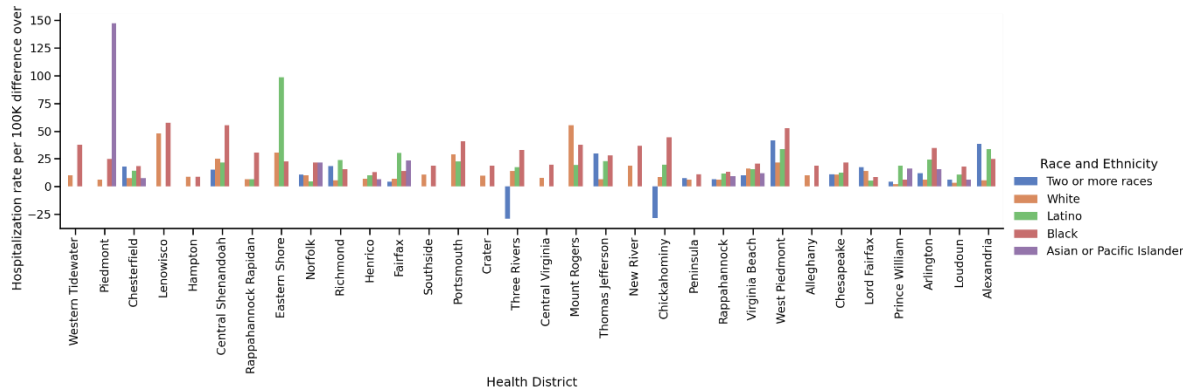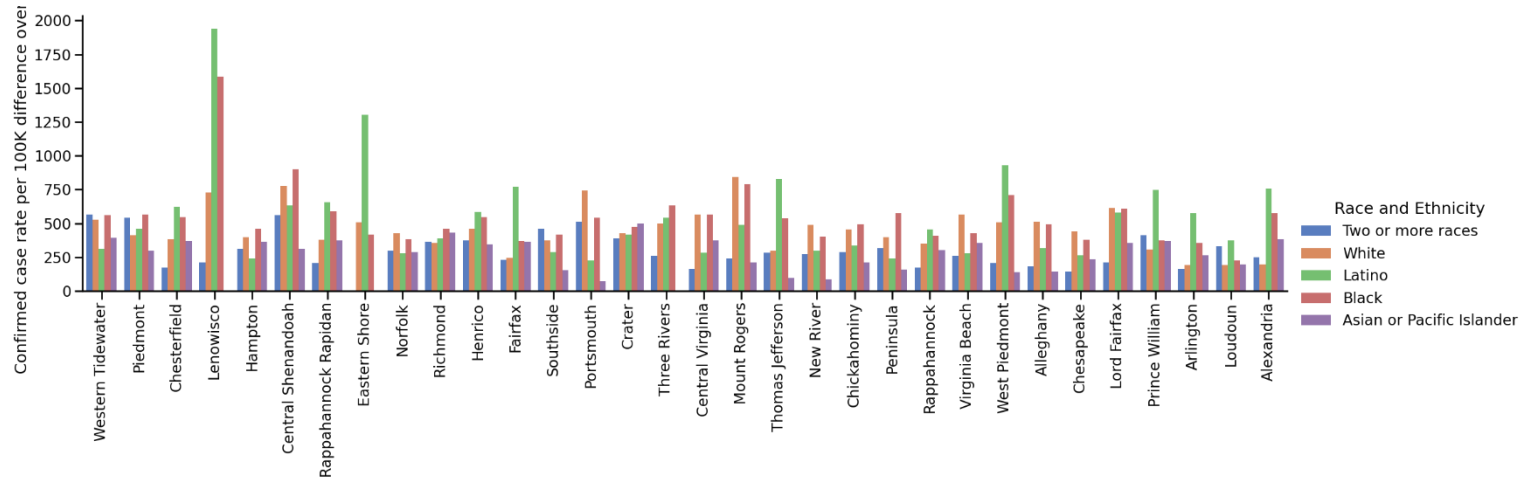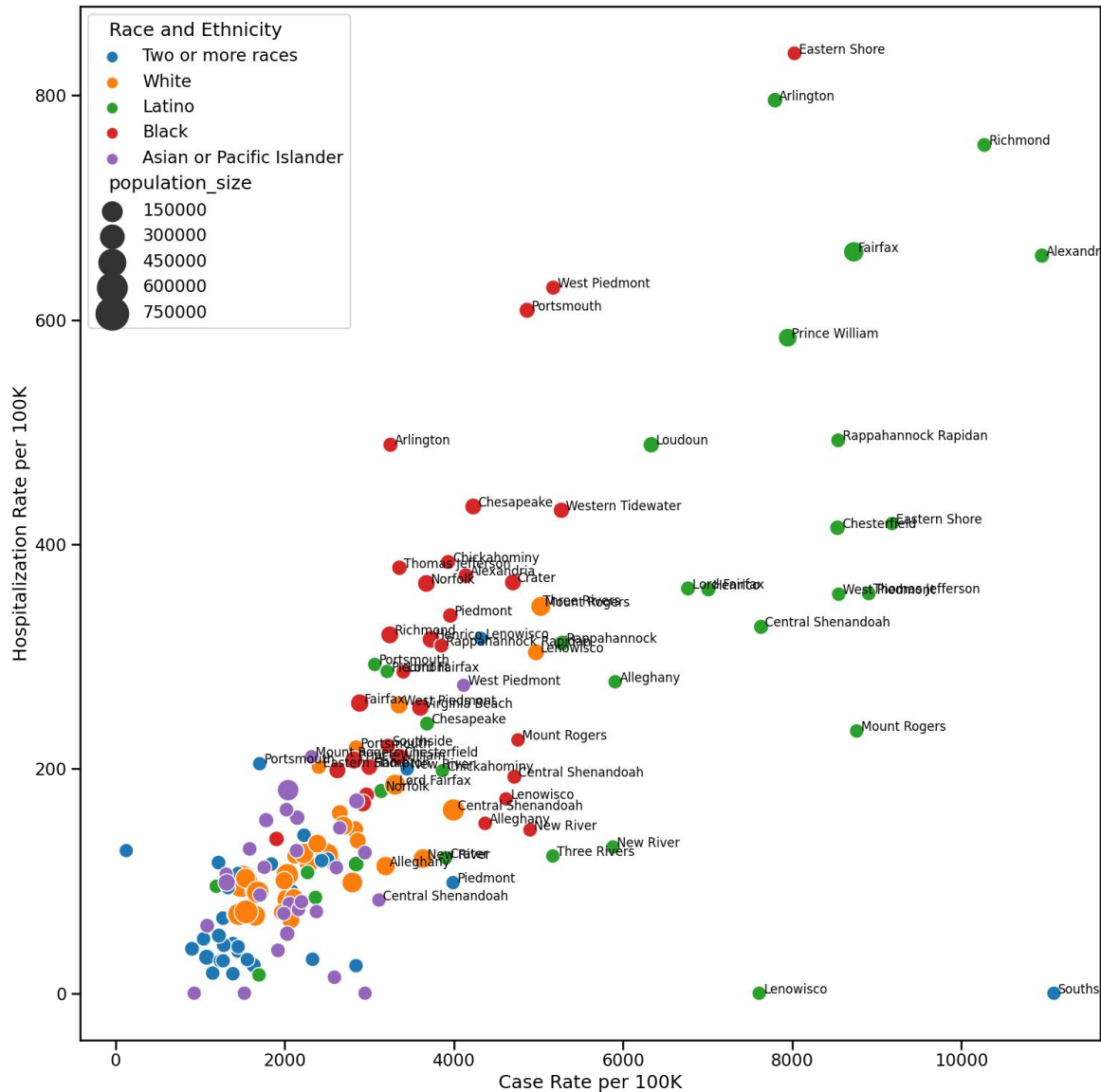
Race and Ethnicity cases per 100K

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

VDH 7-day moving average rate of new COVID-19 cases by zip code average household income (dollars/ household years) quantile
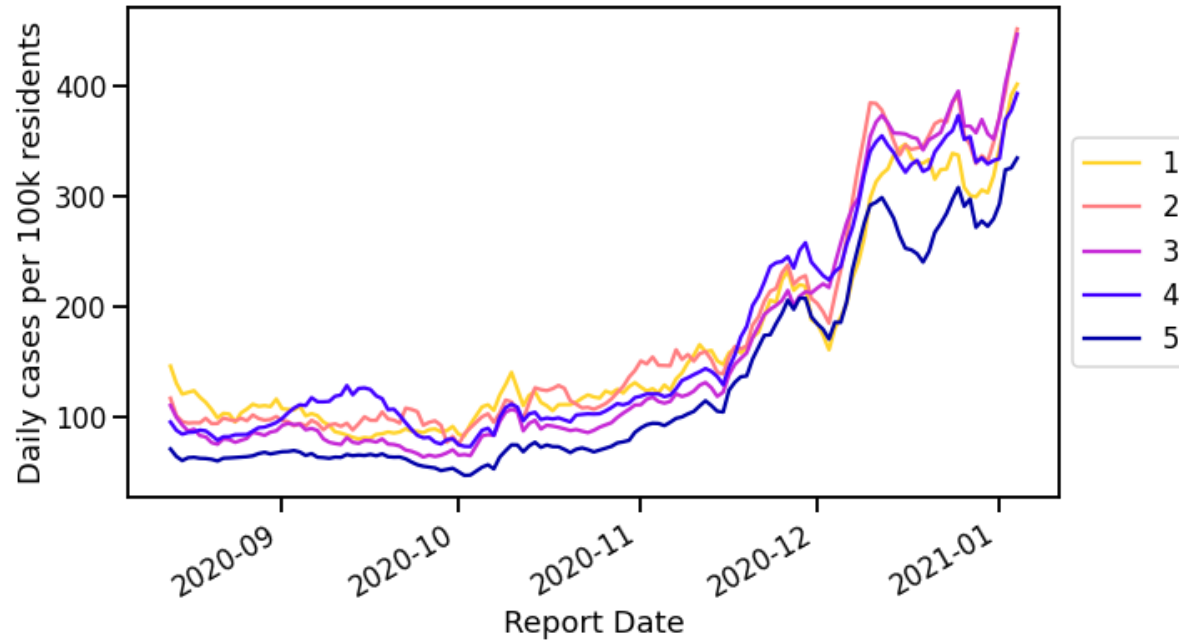
All zip codes show back into growth, wealthiest zip code now lags the rest significantly

VDH mean cases per 100k by zip code population density (person/ sq mile) and average household income (dollars/ household years) quantiles
08/01/20 - 08/07/20
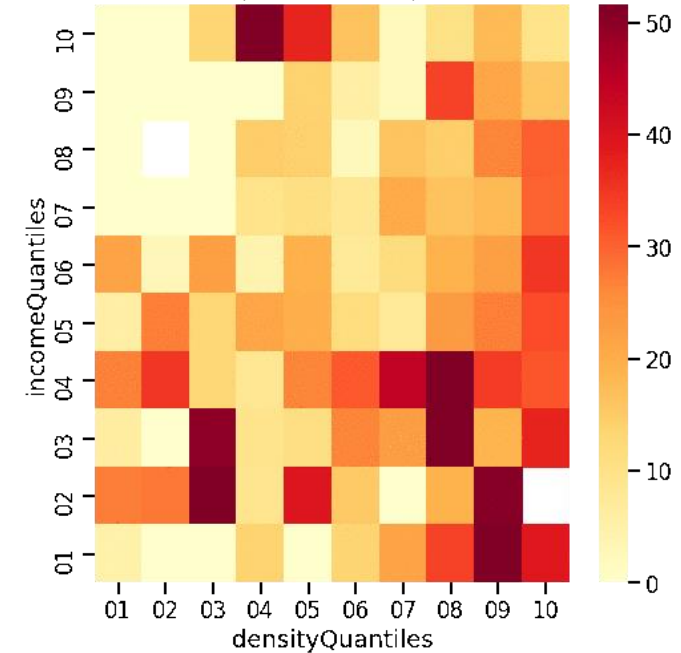
Full evolution of pandemic, shows shifts from denser and wealthier zip codes to poorer and less dense zip codes

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Other State Comparisons

Trajectories of States
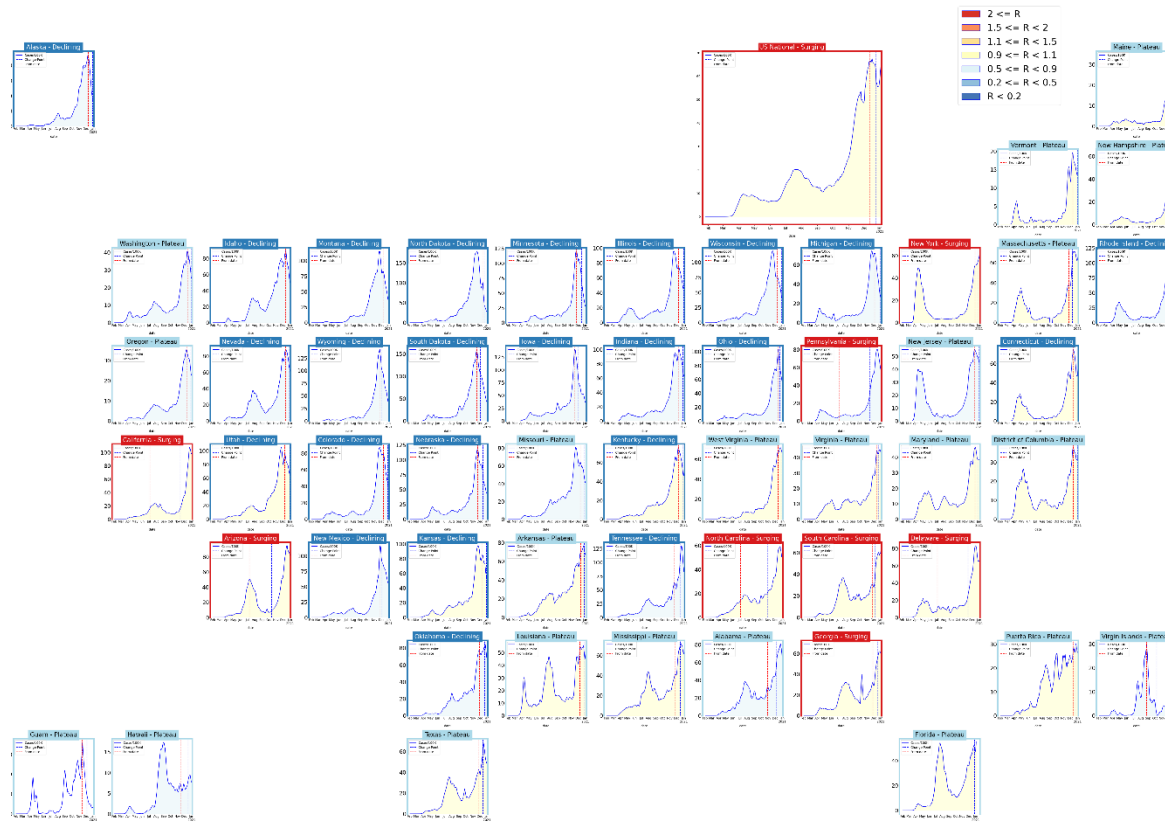
- Many of the states with huge surges in past 6 weeks are subsiding

Virginia and her neighbors

- VA slows its growth and is currently plateaued at a high level
- Most surging states (only 8) are in and around mid-Atlantic
- Many neighbors have plateaued, or are declining

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Zip code level weekly Case Rate (per 100K)

Case Rates in the last week by zip code

- Several of the top ten zip codes are home to prisons,

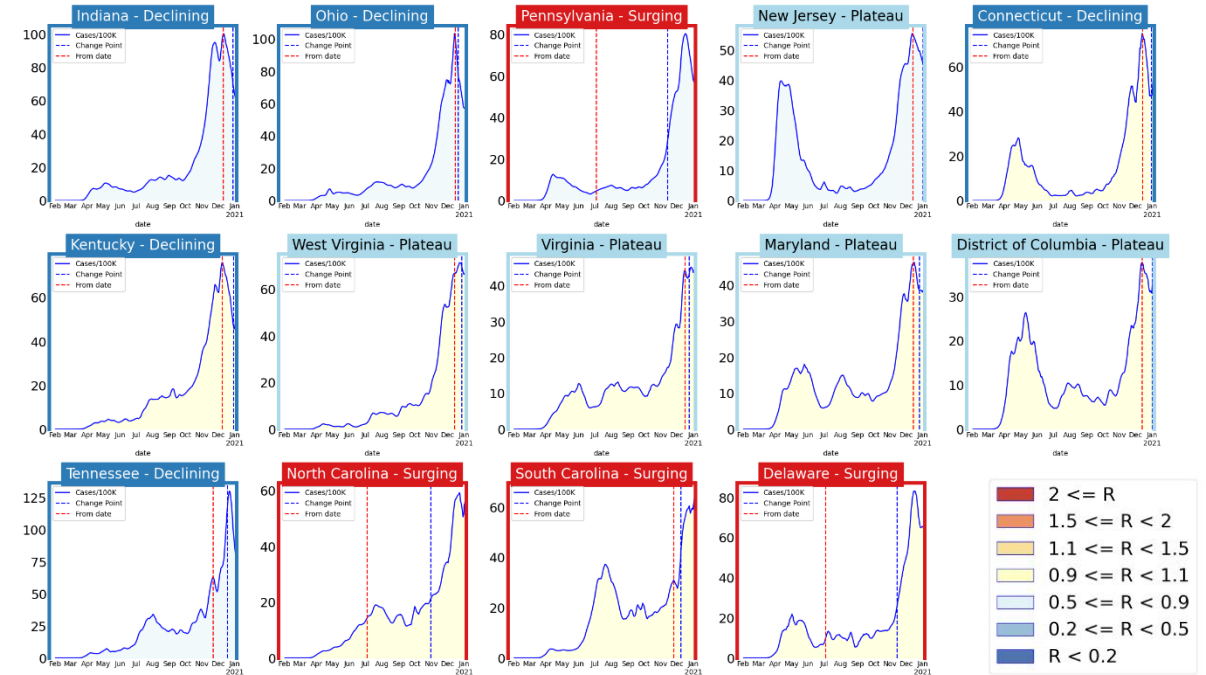- Some counts are low and suppressed to protect anonymity, those are shown in white

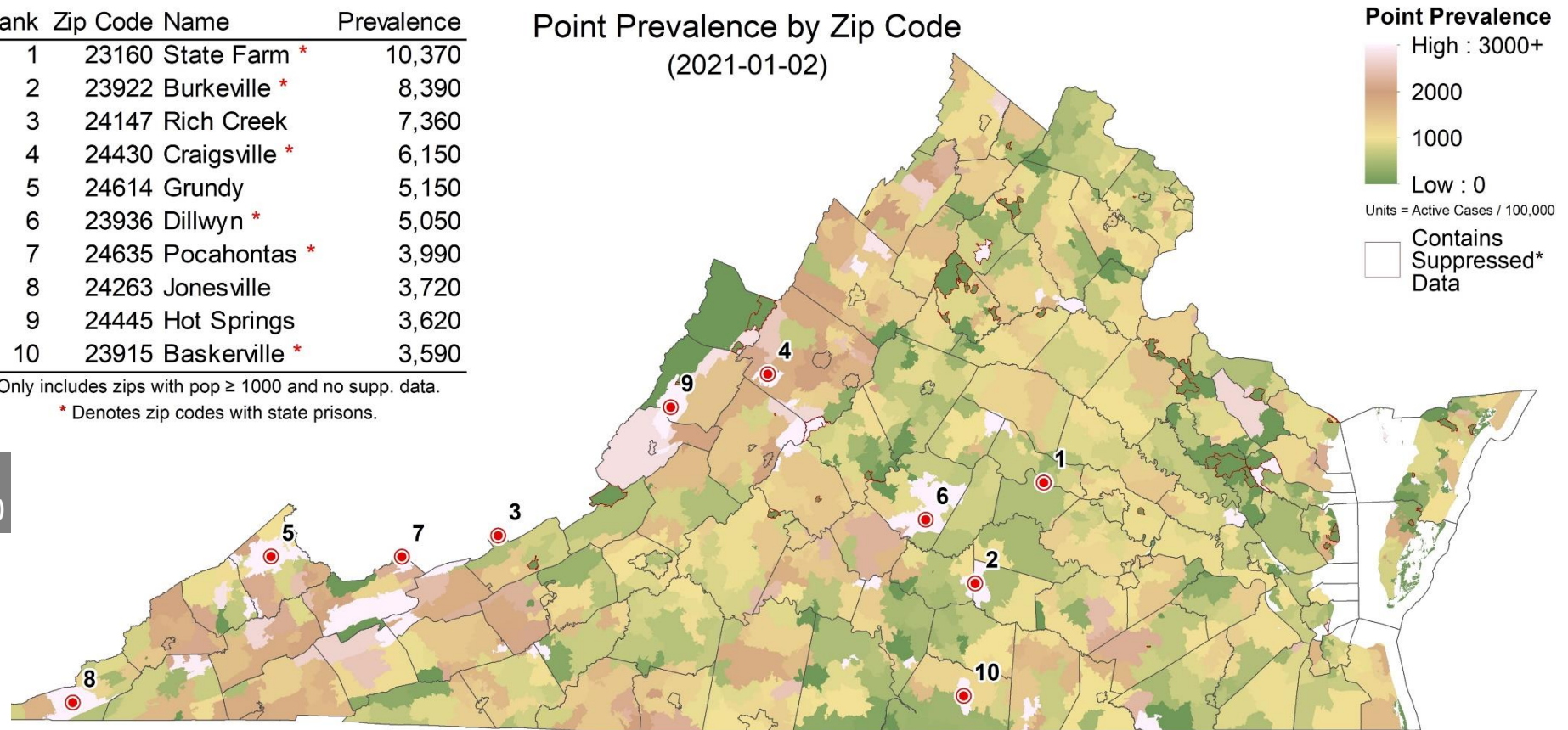| Rank	Zip Code	Name	Prevalence
1	23160	State Farm *	10,370
2	23922	Burkeville *	8,390
3	24147	Rich Creek	7,360
4	24430	Craigsville *	6,150
5	24614	Grundy	5,150
6	23936	Dillwyn *	5,050
7	24635	Pocahontas *	3,990
8	24263	Jonesville	3,720
9	24445	Hot Springs	3,620
10	23915	Baskerville *	3,590

Only includes zips with pop ≥ 1000 and no supp. data.

* Denotes zip codes with state prisons.

Top 10 excluding prisons

Zip code	Name	Weekly Case Rate (per 100K)
24147	Rich Creek	7358
24614	Grundy	5149
24263	Jonesville	3715
24445	Hot Springs	3620
23084	Kents Store	3465
22834	Linville	3387
23011	Barhamsville	3148
24651	Tazewell	2973
24637	Pounding Mill	2967
22853	Timberville	2843

Point Prevalence by Zip Code
(2021-01-02)

Point Prevalence

High : 3000+

2000

1000

Low : 0

Units = Active Cases / 100,000

Contains Suppressed* Data

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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)

- Assumes 3 undetected infections per confirmed case (ascertainment rate from recent seroprevalence survey)

- On left, minimum size of a group with a 50% chance an individual is infected by zip code (eg in a group of 20 in Staunton, there is a 50% chance someone will be infected)

- Some zip codes have high likelihood of exposure even in groups of 25

Rank	Zip Code	Name	Group Size
1	23160	State Farm *	6
2	23922	Burkeville *	8
3	24147	Rich Creek	9
4	24430	Craigsville *	11
5	24614	Grundy	13
6	23936	Dillwyn *	13
7	24635	Pocahontas *	17
8	24263	Jonesville	18
9	24445	Hot Springs	19
10	23915	Baskerville *	19

Only includes zips with pop ≥ 1000 and no supp. data.
* Denotes zip codes with state prisons.

Group Size Needed for 50%
Likelihood of ≥1 Infected

Group Size
High : 300+	
260	
220	
180	
140	
100	
60	
Low : 20	
NaN	
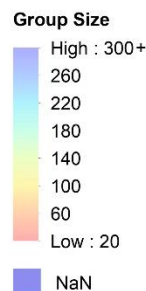
Rank	Zip Code	Name	Likelihood
1	23160	State Farm *	94%
2	23922	Burkeville *	89%
3	24147	Rich Creek	85%
4	24430	Craigsville *	80%
5	24614	Grundy	73%
6	23936	Dillwyn *	73%
7	24635	Pocahontas *	64%
8	24263	Jonesville	61%
9	24445	Hot Springs	60%
10	23915	Baskerville *	60%

Only includes zips with pop ≥ 1000 and no supp. data.
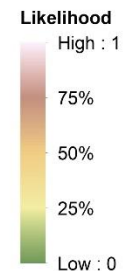* Denotes zip codes with state prisons.

Likelihood of ≥1 Infected Members
(Group of 25)

Likelihood
High : 1	
75%	
50%	
25%	
Low : 0	

Based on zip code point prevalence for week ending 2021-01-02

Based on zip code point prevalence for week ending 2021-01-02

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New variants of SARS-CoV2

Emerging new variant with increased transmissibility but no evidence of higher severity

- Aliases: Variant VUI 202012/01 and Lineage B.1.1.7

- Variant has been detected in CA, FL, CO, GA, and NY; most without travel history indicating local transmission

- This variant is still detected by PCR, and can be detected by proxy with an "S dropout"

- Evolution expected when virus under selective pressure

- Unlikely to alter efficacy of vaccines or other immune treatments

- NERVTAG suggests that "*VUI-202012/01 demonstrates a substantial increase in transmissibility compared to other variants*"

- Another South African variant (501Y.V2) has sparked concern as its mutations may change efficacy of vaccines and other immunological treatments

nextstrain.org

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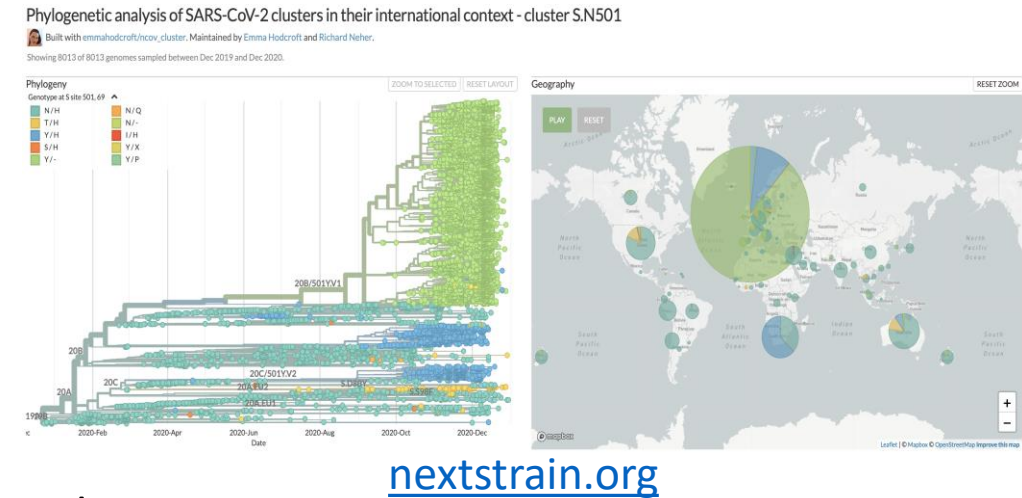
Model Update – Adaptive Fitting

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Adaptive Fitting Approach

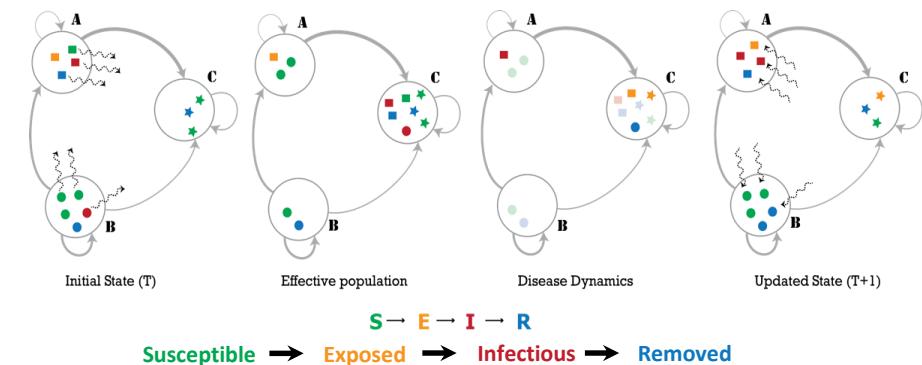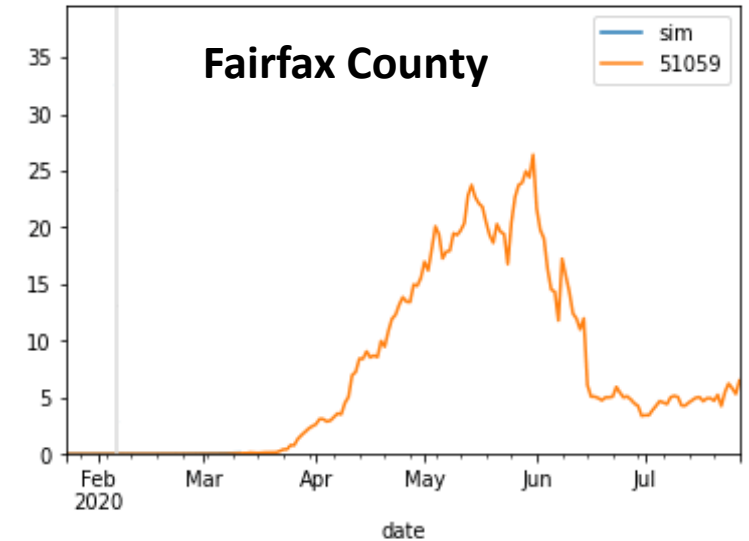**Each county fit precisely, with recent trends used for future projection**

- 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

Fairfax County

S → E → I → R

Susceptible → Exposed → Infectious → Removed

Initial State (T)   Effective population   Disease Dynamics   Updated State (T+1)

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Using Ensemble Model to Guide Projections

An ensemble methodology that combines the Adaptive Fitting and machine learning and statistical models has been developed and refined

- **Models**: Adaptive Fitting, ARIMA, LSTM, AR, spatially driven AR, Kalman Filters (ENKF)

- This approach facilitates the use of other data streams (weather, mobility, etc.)

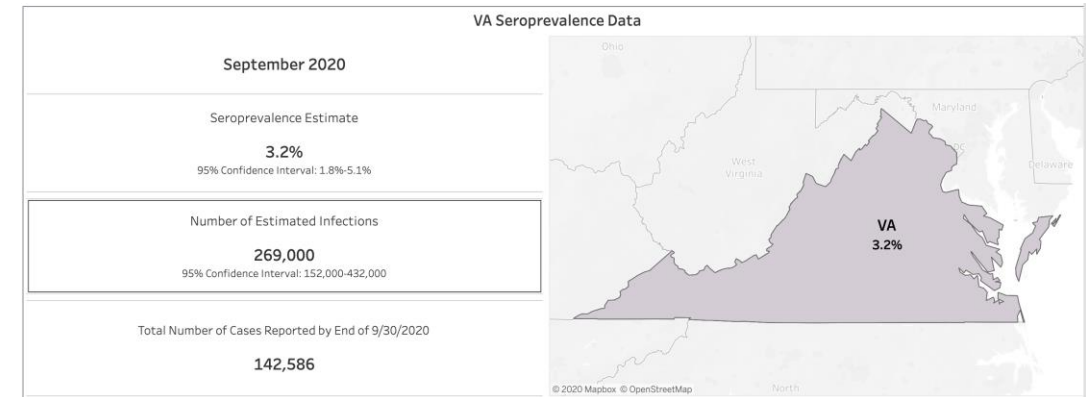- Ensemble provides scaffolding for the Adaptive Fitting's short-term projections

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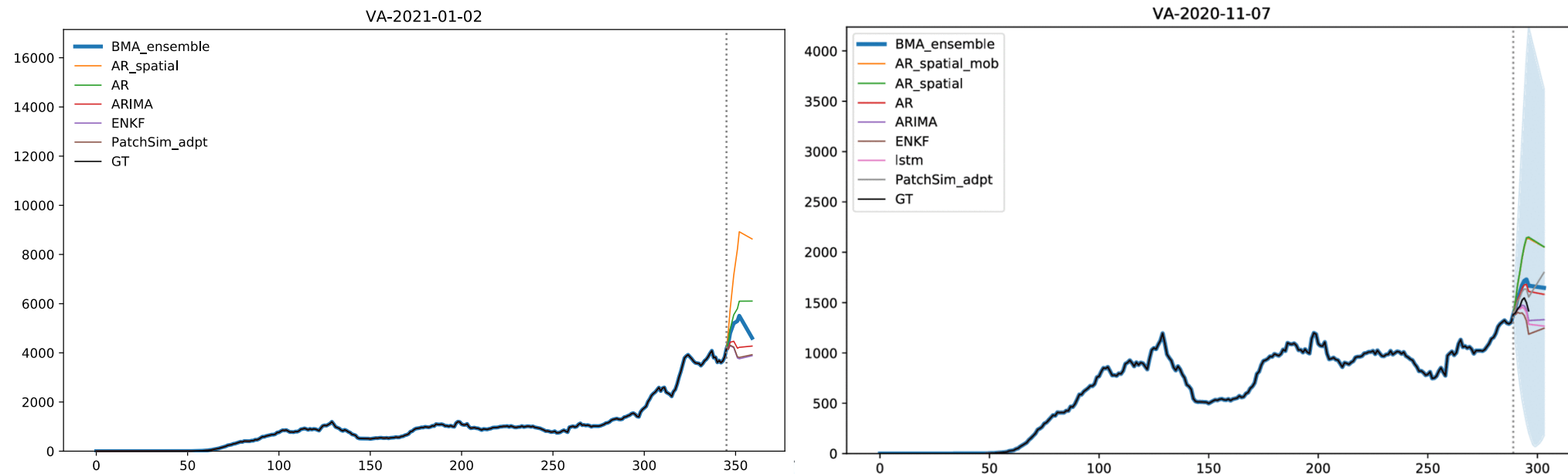
Seroprevalence updates to model design

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 15th)

- CDC Nationwide Commercial Laboratory Seroprevalence Survey estimated 4.1% [2.4% – 6.2%] seroprevalence as of Oct 9th-21st up from 3.2% a month earlier

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)

VA Seroprevalence Data

September 2020

Seroprevalence Estimate
3.2%
95% Confidence Interval: 1.8%-5.1%

Number of Estimated Infections
269,000
95% Confidence Interval: 152,000-432,000

Total Number of Cases Reported by End of 9/30/2020
142,586

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	(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

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Calibration Approach

- **Data:**
  - County level case counts by date of onset (from VDH)
  - Confirmed cases for model fitting

- **Calibration:** fit model to observed data and ensemble's forecast
  - 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 generated using the collection of fit models run into the future
  - **Mean trend from last 14 days of observed cases and first week of ensemble's forecast used**
  - Outliers removed based on variances in the previous 3 weeks
  - 2 week interpolation to smooth transitions in rapidly changing trajectories

COVID-19 in Virginia:

Dashboard Updated: 1/5/2021
Data entered by 5:00 PM the prior day.

Cases, Hospitalizations and Deaths

Total Cases*	Total Hospitalizations**	Total Deaths
371,913	18,526	5,191
(New Cases: 4,377)^		

Confirmed† 309,659	Probable† 62,254	Confirmed† 17,882	Probable† 644	Confirmed† 4,572	Probable† 619

* Includes both people with a positive test (Confirmed), and symptomatic with a known exposure to COVID-19 (Probable).
** Hospitalization status at time case was investigated by VDH. This underrepresents the total number of hospitalizations in Virginia.
^New cases represent the number of confirmed and probable cases reported to VDH in the past 24 hours.
† VDH adopted the updated CDC COVID-19 confirmed and probable surveillance case definitions on August 27, 2020. Found here: https://wwwn.cdc.gov/nndss/conditions/coronavirus-disease-2019-covid-19/case-definition/2020/08/05/
Source: Cases - Virginia Electronic Disease Surveillance System (VEDSS), data entered by 5:00 PM the prior day.

Outbreaks

Total Outbreaks*	Outbreak Associated Cases
1,982	45,992

* At least two (2) lab confirmed cases are required to classify an outbreak.

Testing (PCR Only)

Testing Encounters PCR Only*	Current 7-Day Positivity Rate PCR Only**
4,404,641	16.2%

* PCR" refers to "Reverse transcriptase polymerase chain reaction laboratory testing."
** Lab reports may not have been received yet. Percent positivity is not calculated for days with incomplete data.

Multisystem Inflammatory Syndrome in Children

Total Cases*	Total Deaths
13	0

*Cases defined by CDC HAN case definition: https://emergency.cdc.gov/han/2020/han00432.asp

Accessed 8:30am January 6, 2021

https://www.vdh.virginia.gov/coronavirus/

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Scenarios – Seasonal Effects and Vaccines

- 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, viral mutations, 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

- Vaccination has started, focus on priority groups may limit population level effects initially, though small impacts may be observed in early February
  - Initial rollout estimated at 12.5M people in US (~330K in VA) in January, then 25M (~660K) per month, assumes limited impact from any vaccinations in December.
  - Assume all available vaccine is administered and has 80% efficacy in 2 weeks (timing more sensitive than max efficacy in early stages)
  - Counterfactuals with no vaccine ("NoVax") are provided for comparison purposes

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Scenarios – Seasonal Effects and Vaccines

- Three behavioral scenarios capture possible trajectories starting Dec 24th, 2020
  - **Adaptive**: No change from base projection
  - **Adaptive-StrongControl-3w**: 30% decrease in transmission starting Jan 8th, 2021 which lasts for 3 weeks, before returning to same transmission rate as Adaptive
  - **Adaptive-LessControl**: 15% increase in transmission starting Jan 8th, 2021

- Vaccinations are incorporated in "base" projections, counterfactuals without vaccinations provide lower bound on vaccines impact
  - **Adaptive-NoVax**: No change from base projection without vaccine
  - **Adaptive-NoVax-StrongControl-3w**: 30% decrease in transmission starting Jan 8th, 2021 which lasts for 3 weeks, before returning to same rate as Adaptive without vaccine
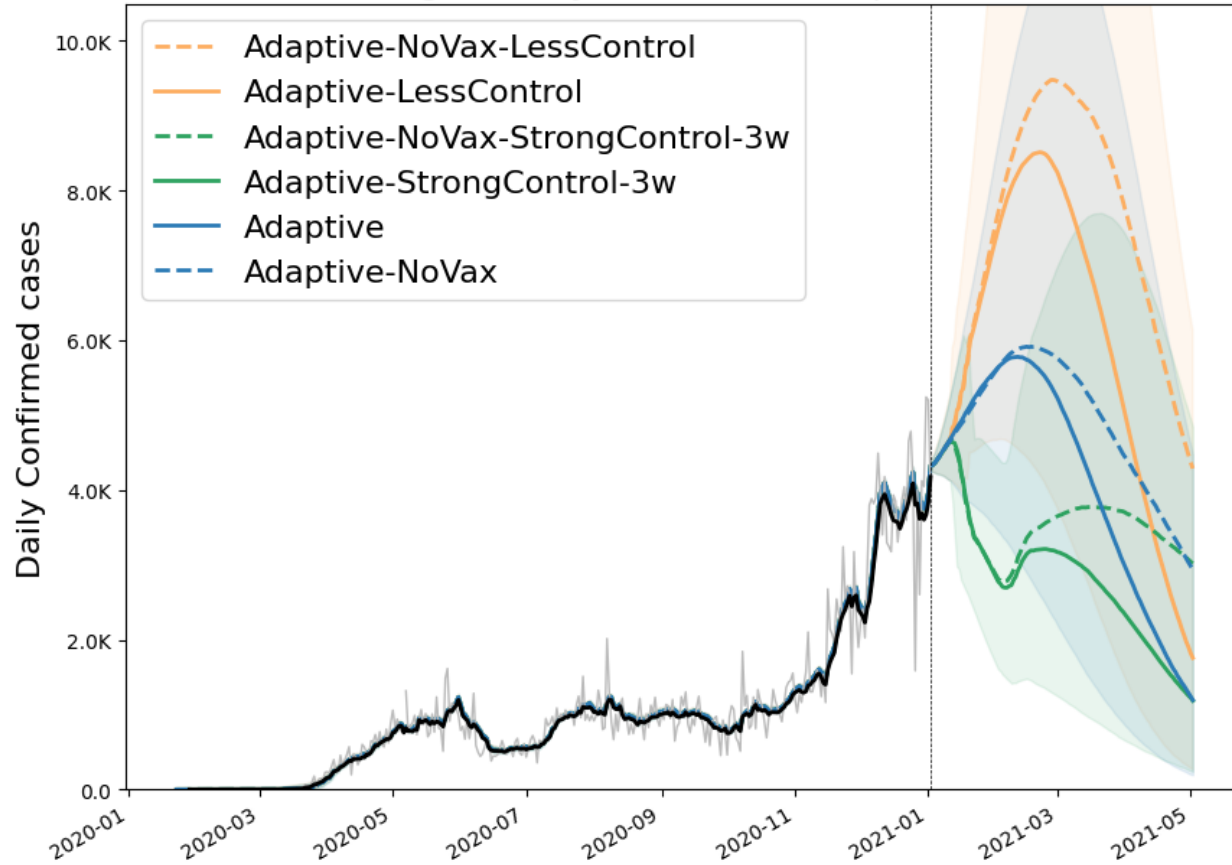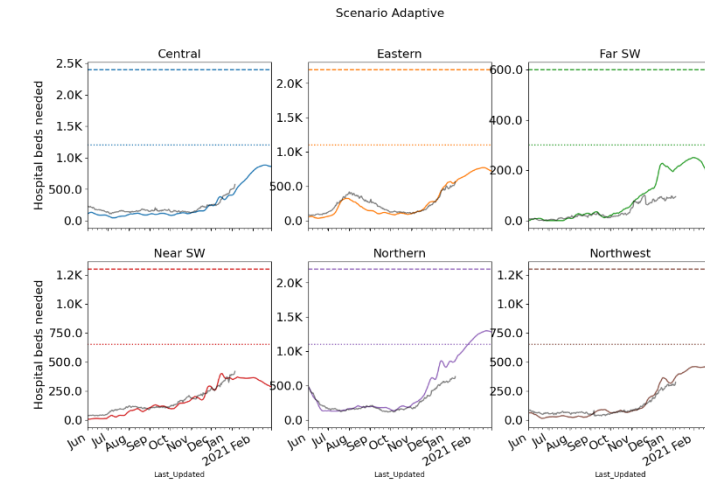 - **Adaptive-NoVax-LessControl**: 15% increase in transmission starting Jan 8th, 2021 without vaccine

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Model Results

Outcome Projections

Estimated Hospital Occupancy

Confirmed cases

Daily Deaths
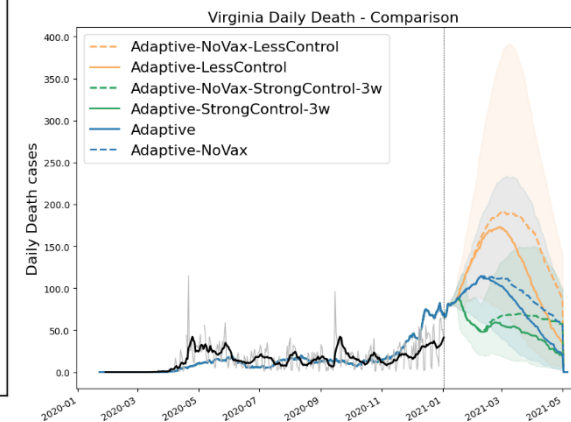
Cumulative Confirmed cases

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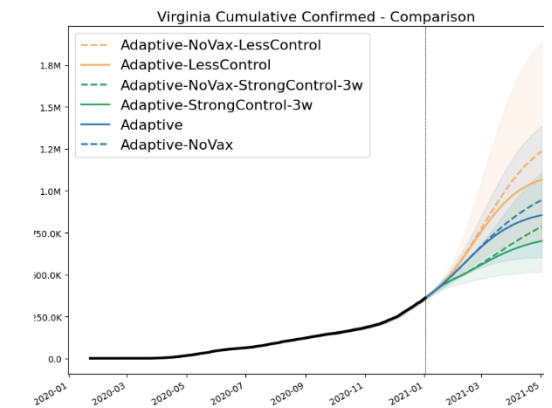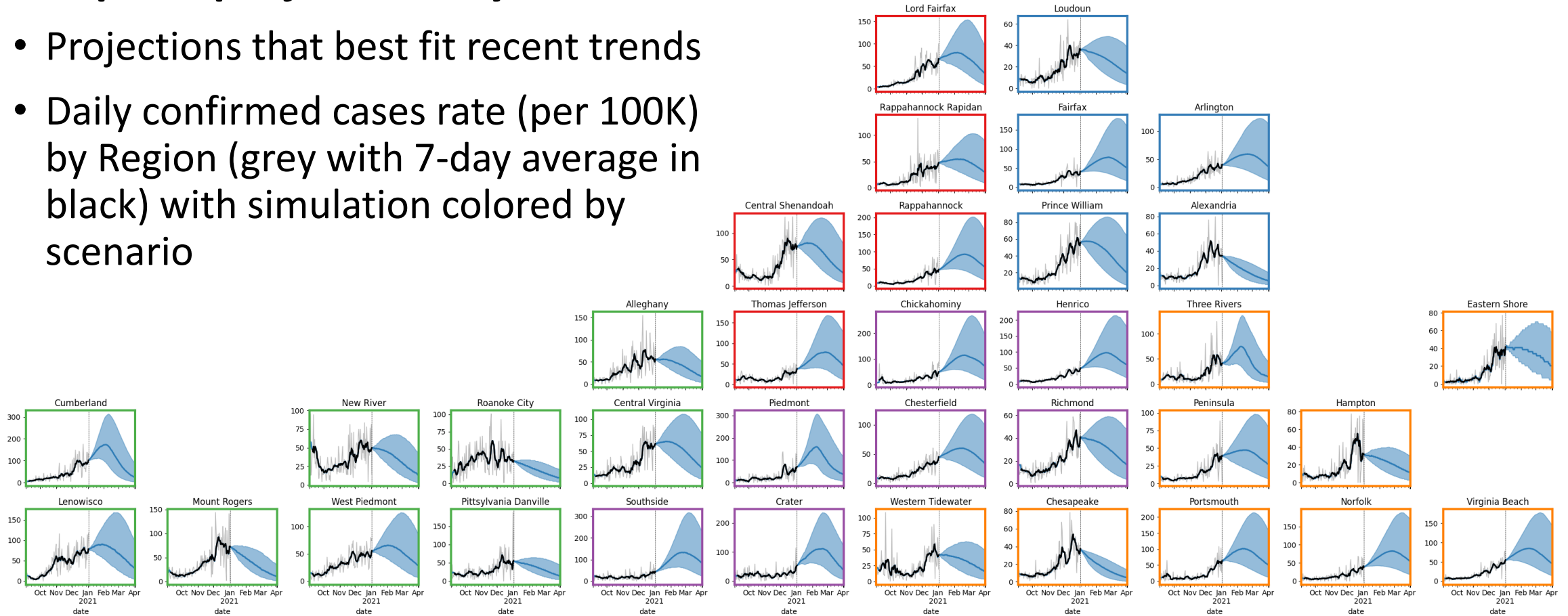
District Level Projections: Adaptive
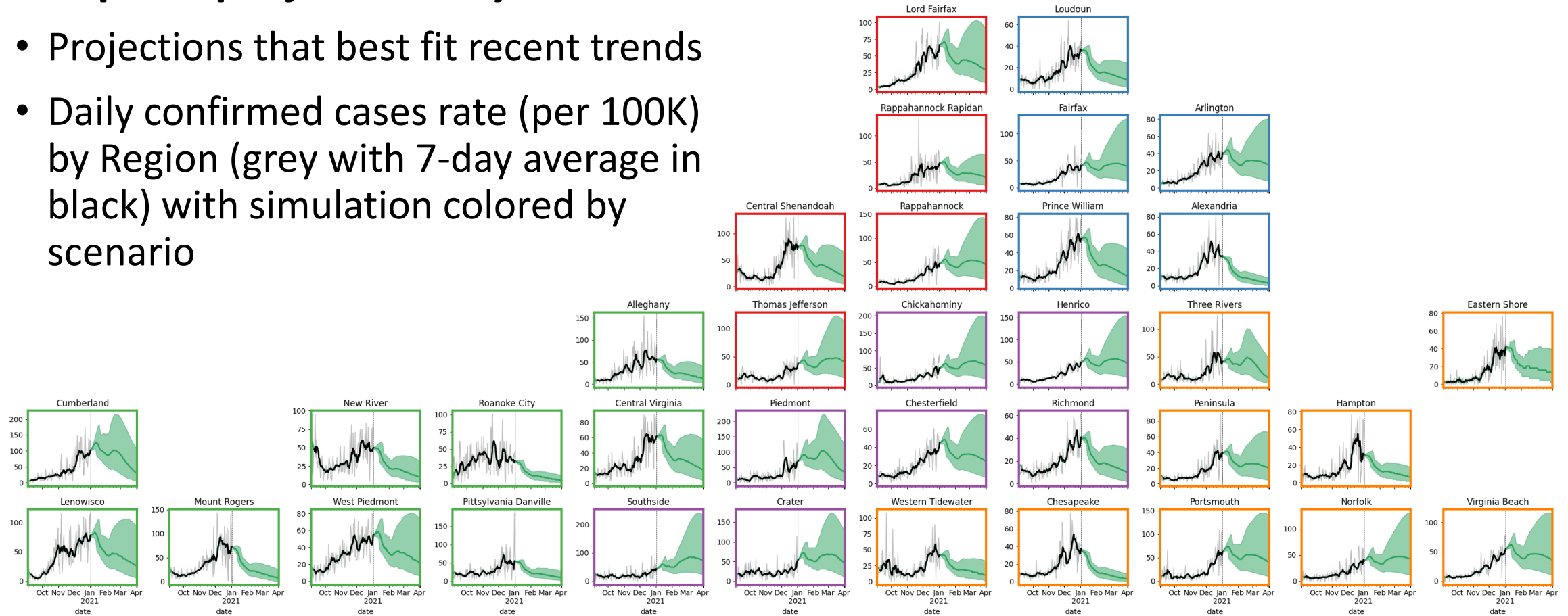
Adaptive projections by District

- Projections that best fit recent trends

- Daily confirmed cases rate (per 100K) by Region (grey with 7-day average in black) with simulation colored by scenario

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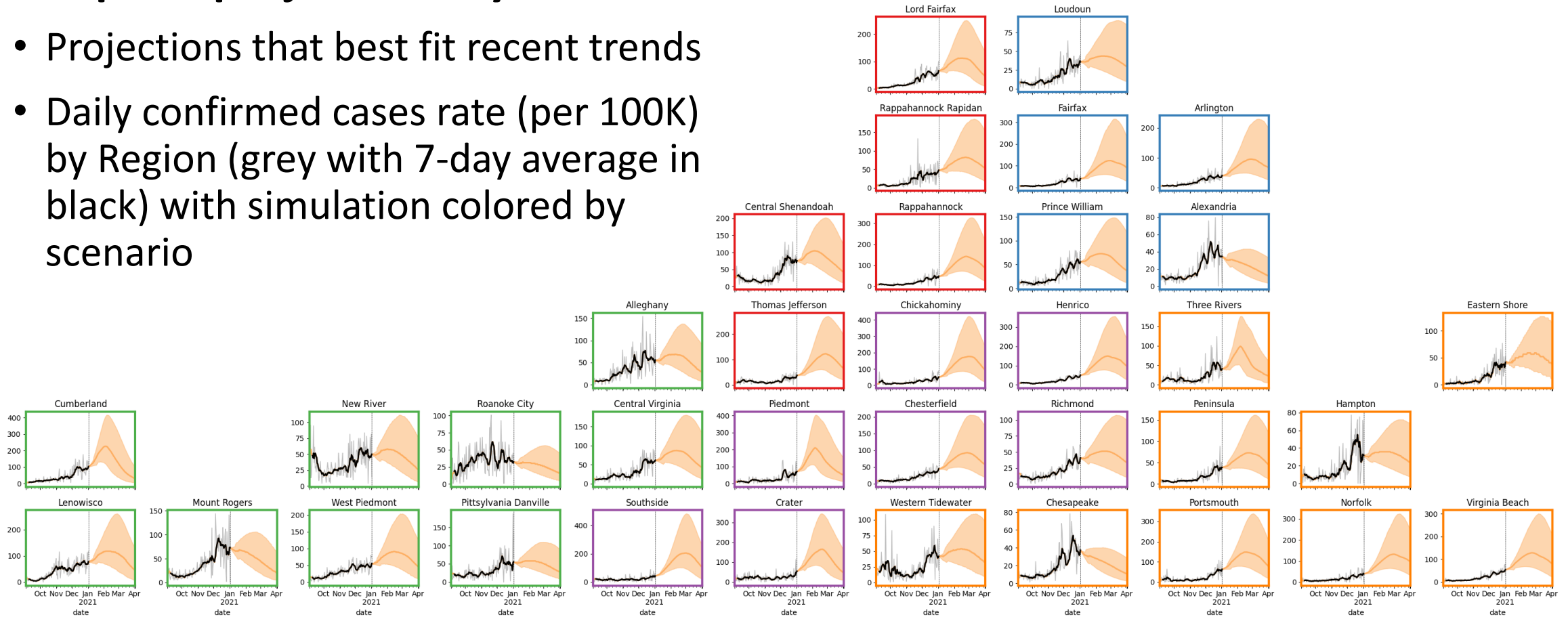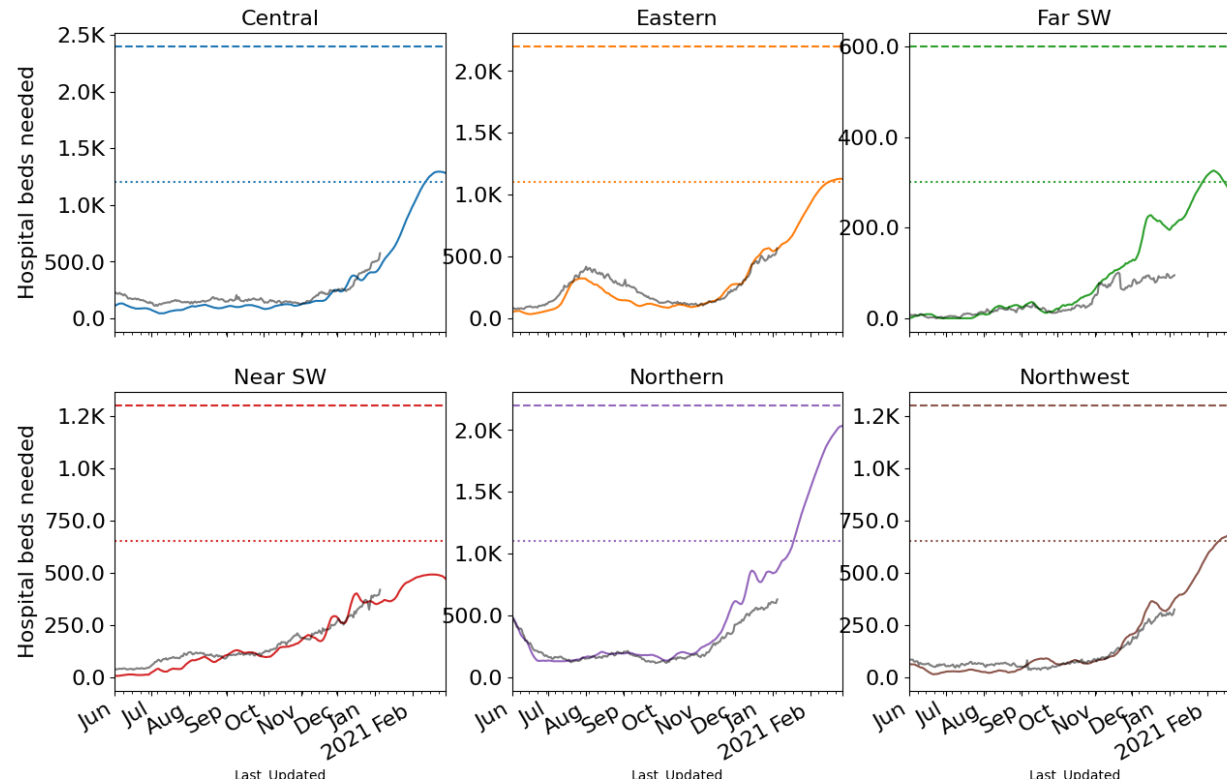
Hospital Demand and Bed Capacity by Region

Capacities* by Region – Adaptive-LessControl

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

Week Ending	Adaptive	Adaptive-LessControl
1/3/21	26,775	26,776
1/10/21	30,339	30,287
1/17/21	32,547	33,891
1/24/21	34,877	40,775
1/31/21	36,893	46,579
2/7/21	38,380	51,867
2/14/21	38,930	55,466
2/21/21	38,292	57,141
2/28/21	36,666	56,817
3/7/21	33,978	54,059
3/14/21	30,707	49,929
3/21/21	27,111	45,228

Weekly confirmed cases

If Adaptive-LessControl scenario persists:

- All regions approach initial bed capacity this winter
- Surge capacity approached in Northern region in Feb to early March

* Assumes average length of stay of 8 days

7-Jan-21

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33

Key Takeaways

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

- **Case rate growth in Virginia has fluctuated through the holidays and is up overall.**

- VA mean weekly incidence (52/100K) up (from 42) as national levels rebound (to 58/100K from 48/100K).

- Projections are mixed across commonwealth but generally up as well.

- Recent updates:

  - Preliminary estimates for vaccination impact

  - Planning scenarios shifted to early January (Jan 8)

  - Added a 3 week "Strong Control" control strategy to scenarios

- Behavioral changes can outpace impact of optimistic vaccine rollout and prevent significantly more cases by Spring.

- The situation is changing rapidly. Models will be updated regularly.

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Arindam Fadikar, Dave Higdon, Jiangzhuo Chen, Bryan Lewis, Srinivasan Venkatramanan, and Madhav Marathe. Calibrating a stochastic, agent-based model using quantile-based emulation. SIAM/ASA Journal on Uncertainty Quantification, 6(4):1685–1706, 2018.

Adiga, Aniruddha, Srinivasan Venkatramanan, Akhil Peddireddy, et al. "Evaluating the impact of international airline suspensions on COVID-19 direct importation risk." *medRxiv* (2020)

NSSAC. PatchSim: Code for simulating the metapopulation SEIR model. https://github.com/NSSAC/PatchSim (Accessed on 04/10/2020).

Virginia Department of Health. COVID-19 in Virginia. http://www.vdh.virginia.gov/coronavirus/ (Accessed on 04/10/2020)

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/

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Questions?

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Supplemental Slides

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Estimating Daily Reproductive Number

Dec 11ᵗʰ Estimates

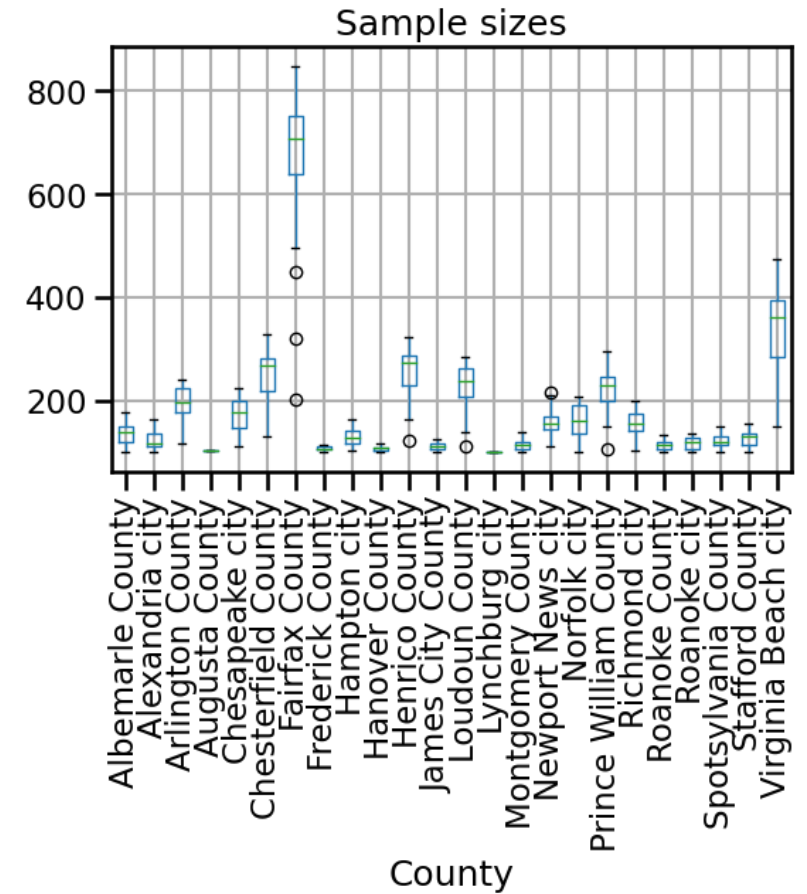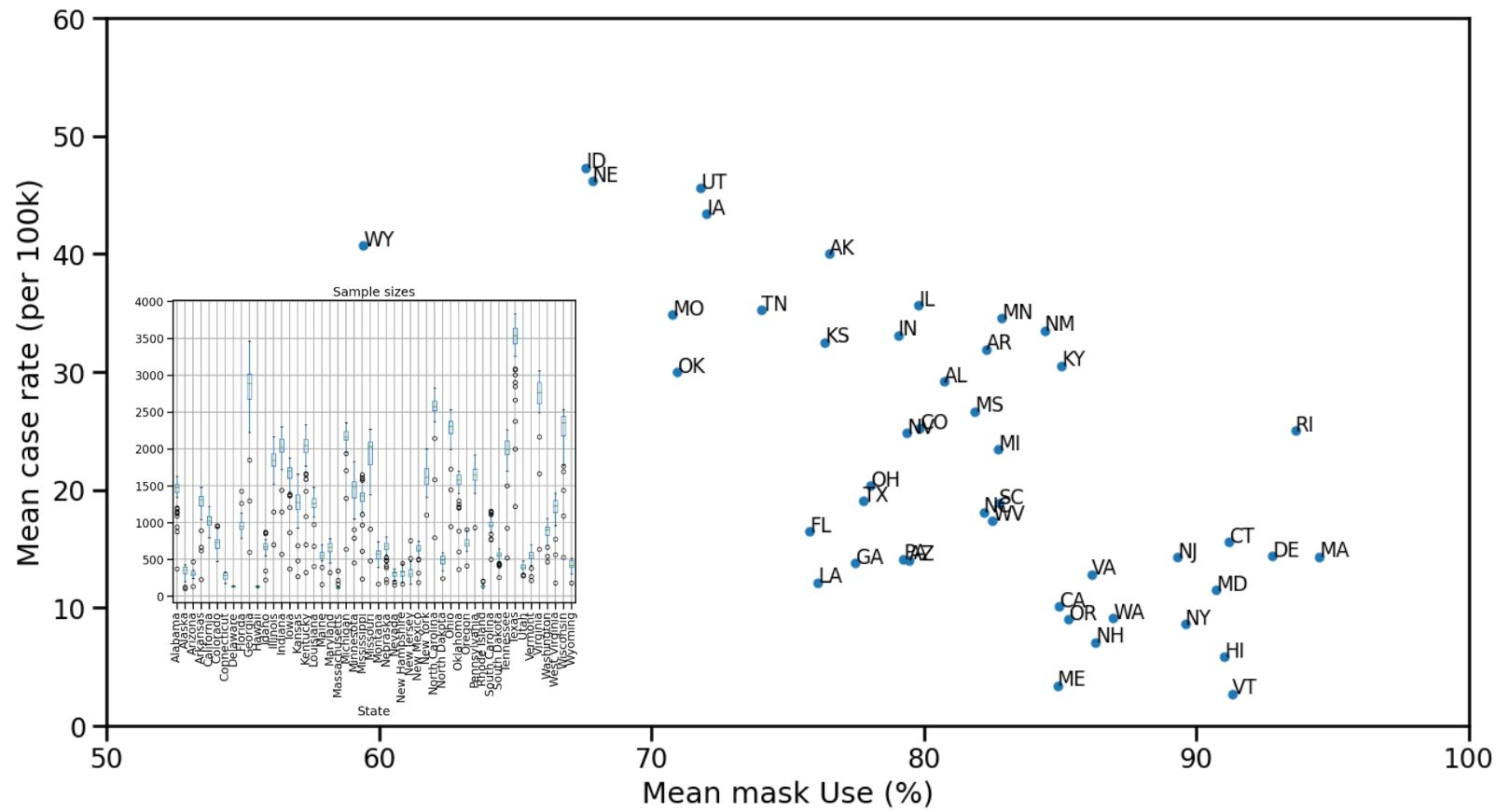| Region	Date of Onset R_e	Date Onset Diff Last Week
State-wide	0.977	-0.275
Central	0.854	-0.491
Eastern	1.009	-0.176
Far SW	1.083	-0.323
Near SW	0.988	-0.301
Northern	0.949	-0.253
Northwest	1.054	-0.193

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

VA state-wide RE with 7 day moving window by date of onset 12/20/20

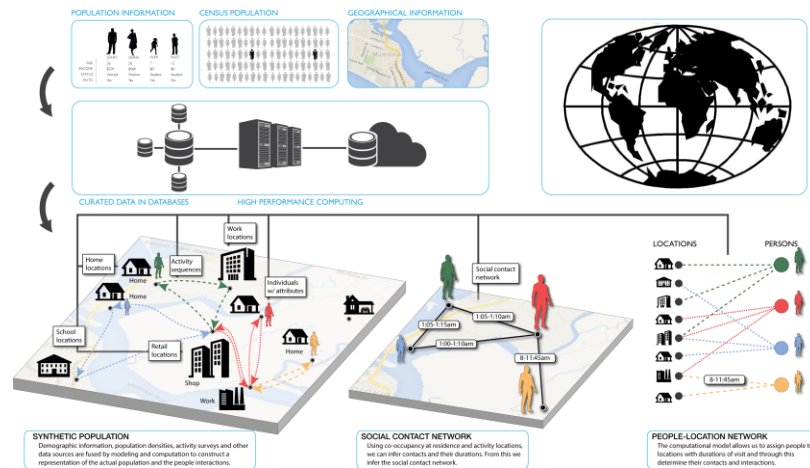VA RE by VHASS region with 7 day moving window by date of onset 12/20/20
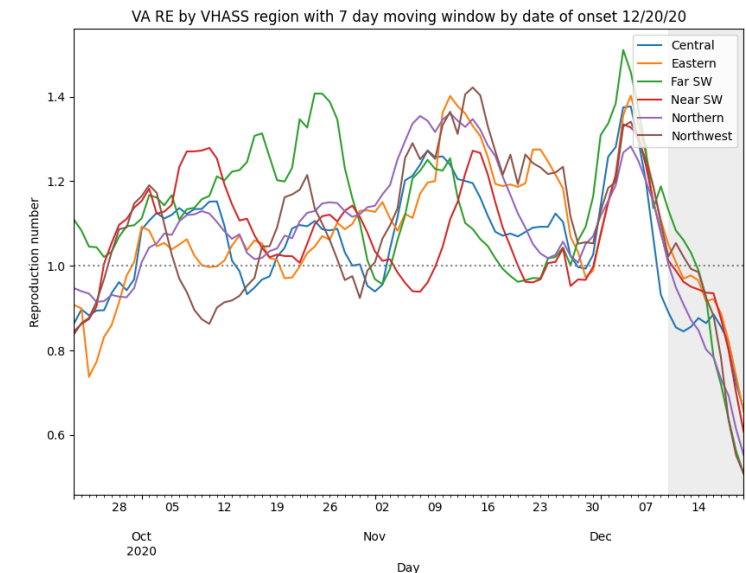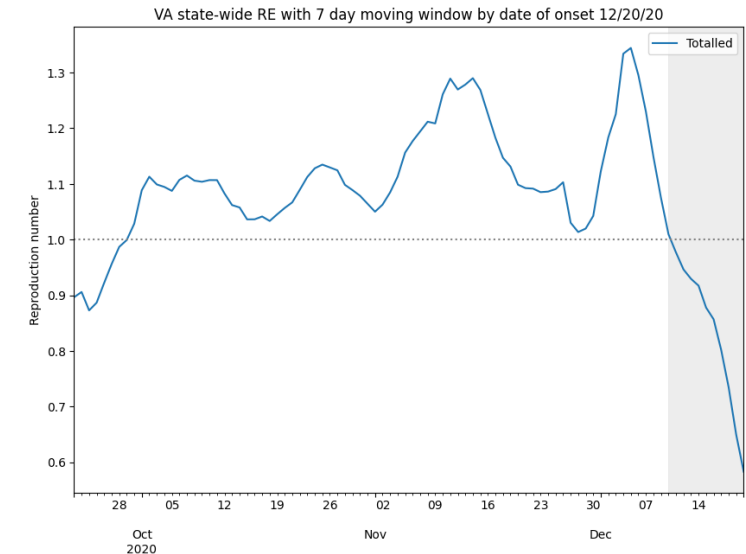
Mask usage sample sizes
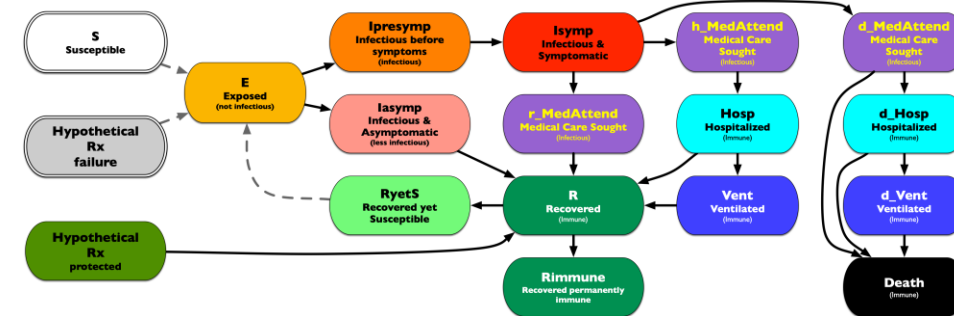
Agent-based Model (ABM)

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"
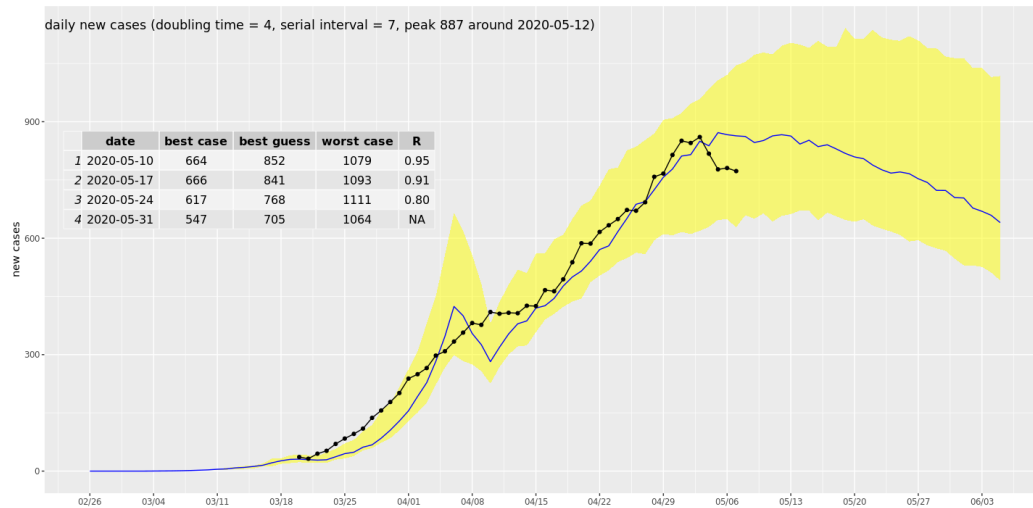
Calibration to Current State

- Adjust transmission and adherence to current policies to current observations
- For Virginia, with same seeding approach as PatchSim
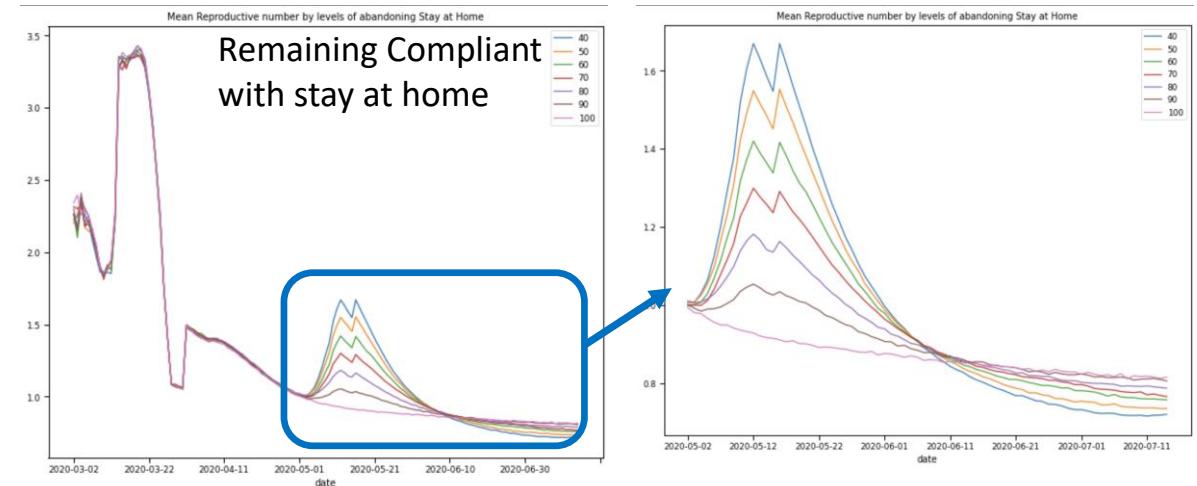
Impacts on Reproductive number with release

- 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

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Medical Resource Demand Dashboard

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