Network Systems
Science & Advanced
Computing

Biocomplexity Institute
& Initiative

University of Virginia

Estimation of COVID-19 Impact in Virginia

January 20th , 2021

(data current to January 18th-19th)

Biocomplexity Institute Technical report: TR 2021-006

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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

Key Takeaways

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

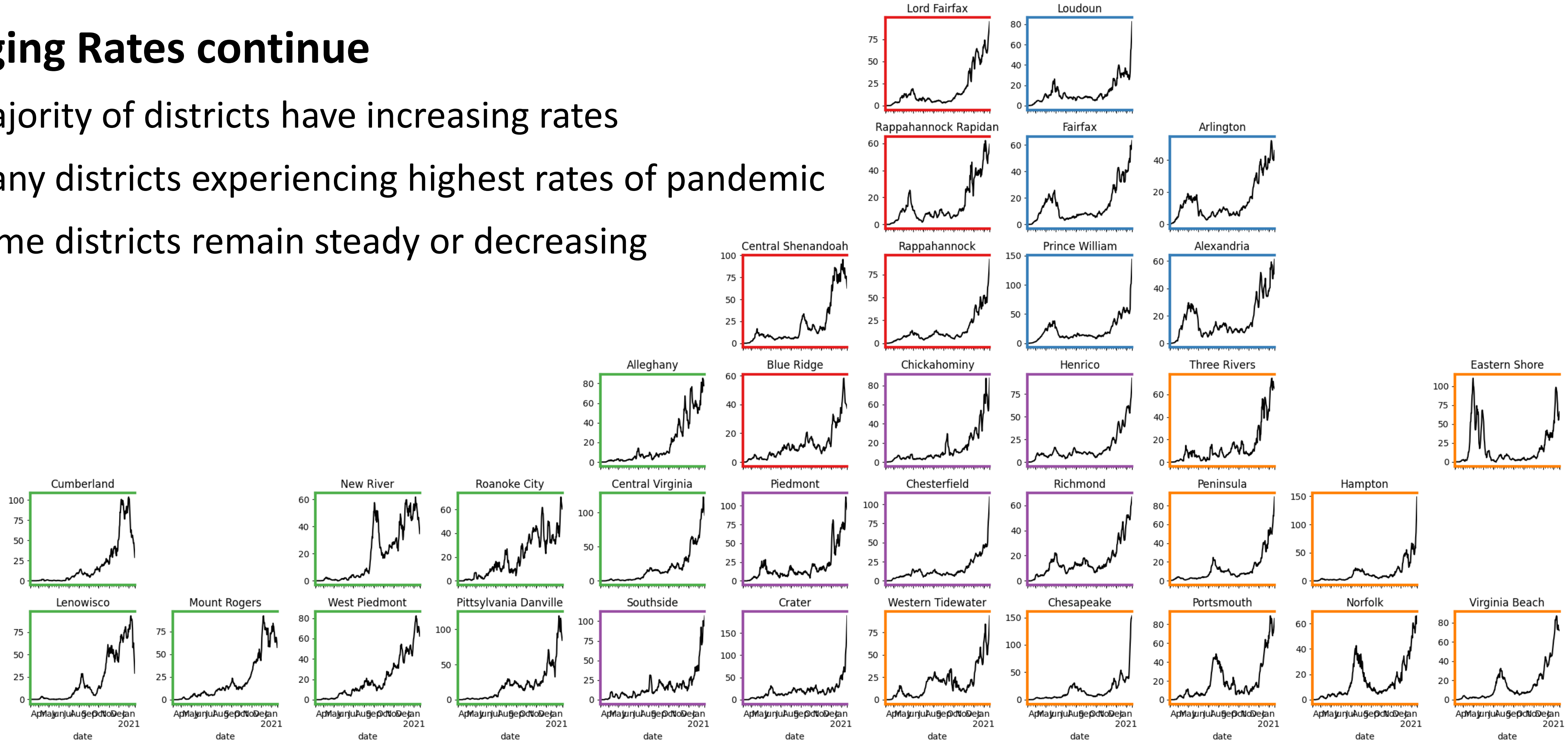
- **Case rate growth in Virginia continues to surge with some signs of slowing as national levels subside**
- VA mean weekly incidence up to 72/100K from 60/100K, as national levels decline (to 54/100K from 67/100K); Virginia records highest daily case rate in past week (116/100K on Jan 17th) and weekly average is above national average
- Projections are mixed across commonwealth with overall short-term growth at state level
- Recent updates:
  - Modified scenarios to be based on past control levels (best and fatigued)
  - Added a scenario based on emerging new variants with enhanced transmissibility
  - Refined vaccination schedule to account for partial protection from first dose and merged with current vaccines administered to date
- The situation is changing rapidly. Models will be updated regularly.

Situation Assessment

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



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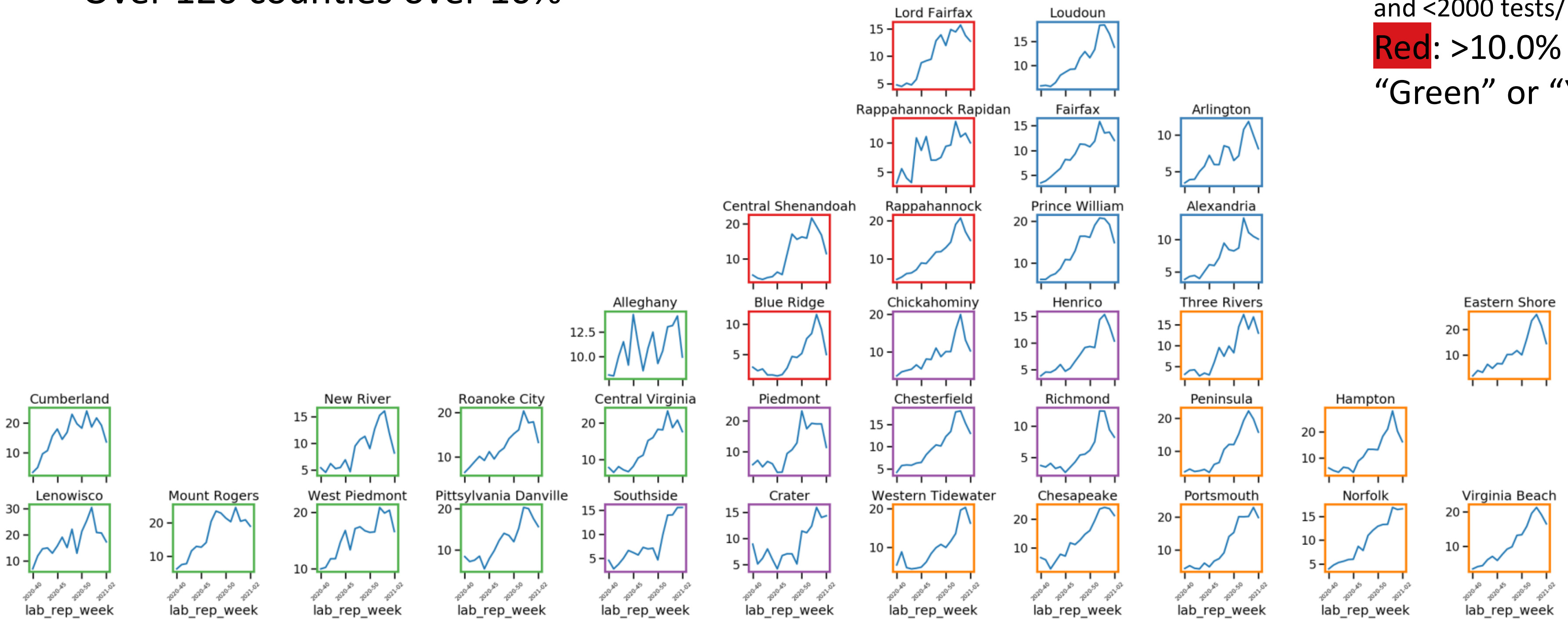
Test Positivity by VDH District

Weekly changes in test positivity by district

- Increasing levels in many districts throughout the commonwealth with many districts above 10% for several weeks
- Over 120 counties over 10%

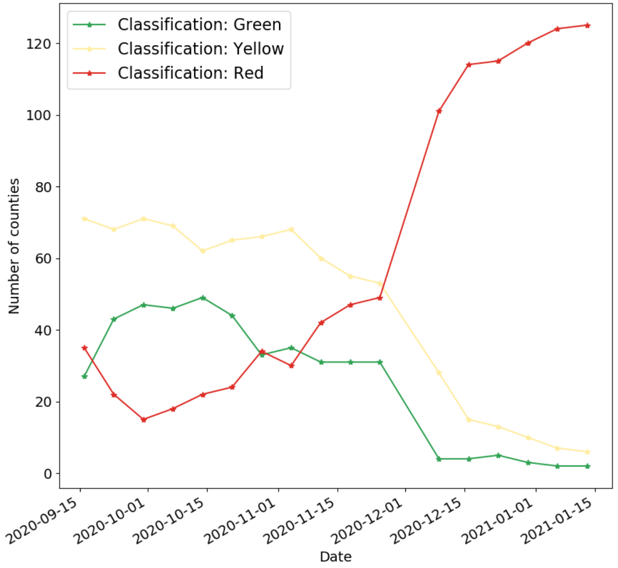


County level test positivity rates for RT-PCR tests.

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"



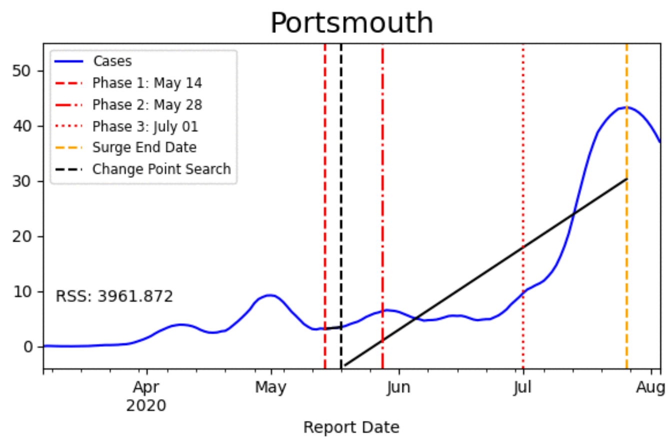
https://data.cms.gov/stories/s/q5r5-gjyu

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 (3)
Plateau	Steady level with minimal trend up or down	above -0.9 and below 0.5	1 (1)
Slow Growth	Sustained growth not rapid enough to be considered a Surge	above 0.5 and below 2.5	11 (14)
In Surge	Currently experiencing sustained rapid and significant growth	2.5 or greater	13 (17)

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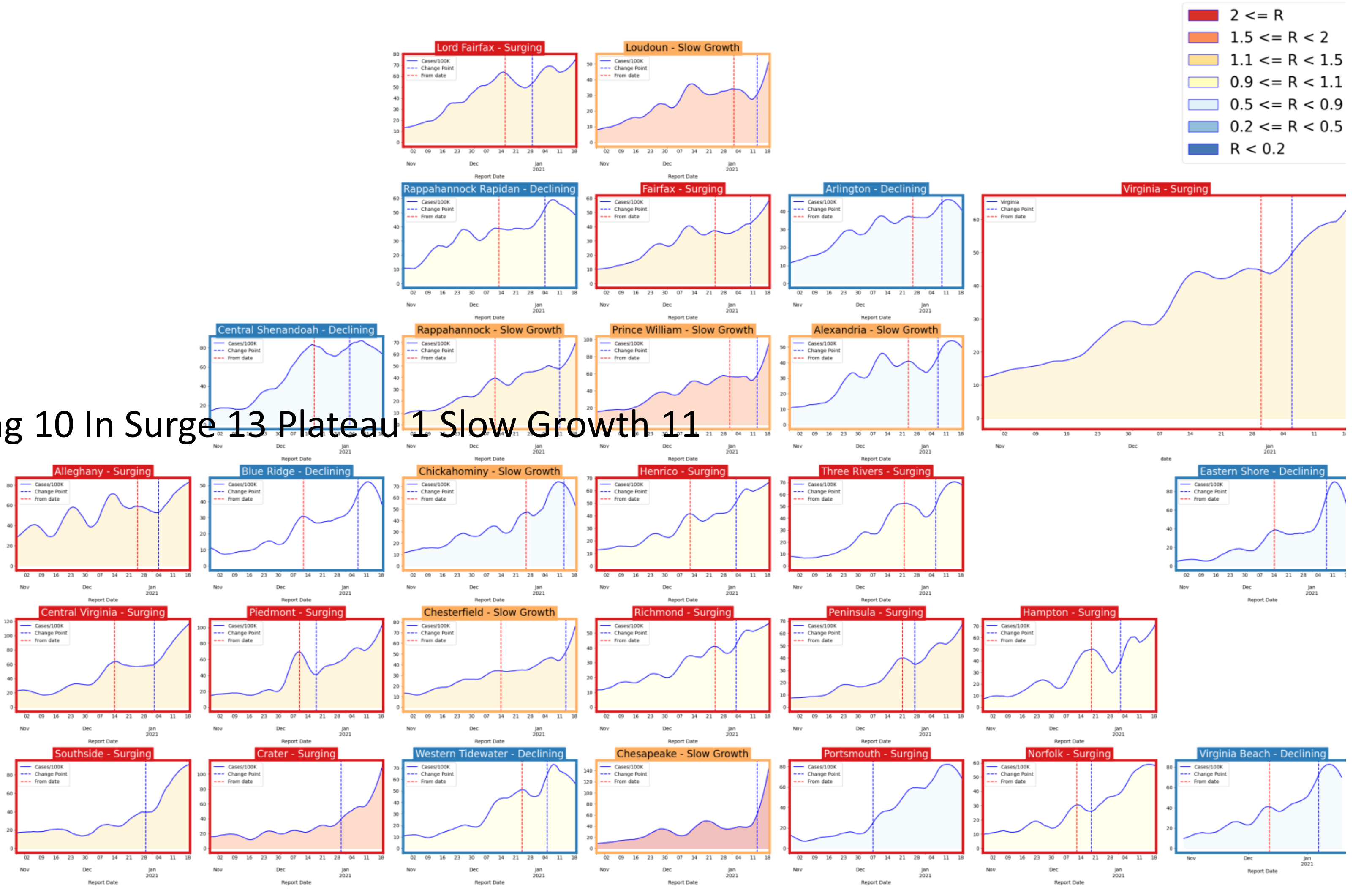
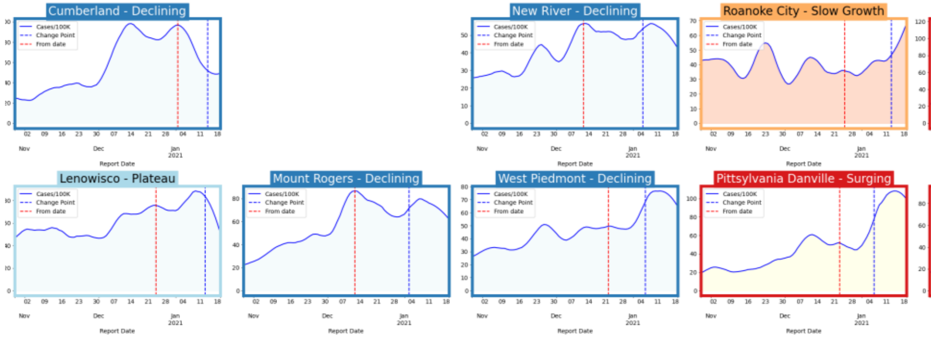
District Trajectories – last 10 weeks

Status	# Districts (prev week)
Declining	10 (3)
Plateau	1 (1)
Slow Growth	11 (14)
In Surge	13 (17)

Declining 10 In Surge 13 Plateau 1 Slow Growth 11

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

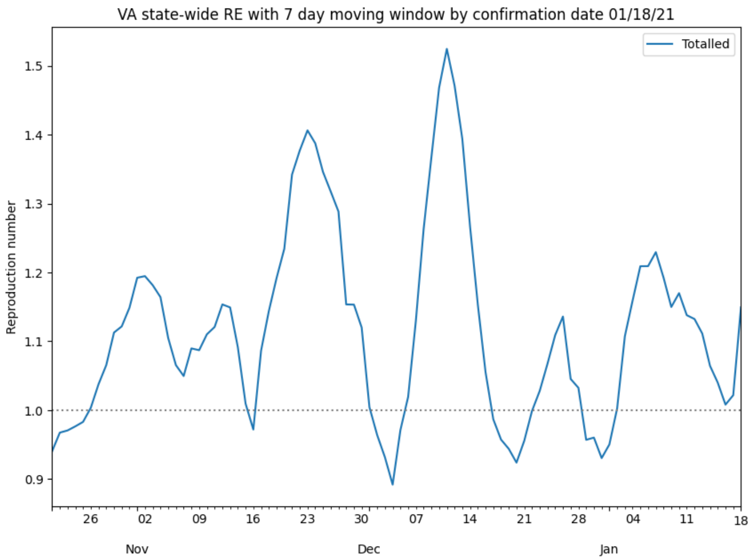
Jan 18th Estimates

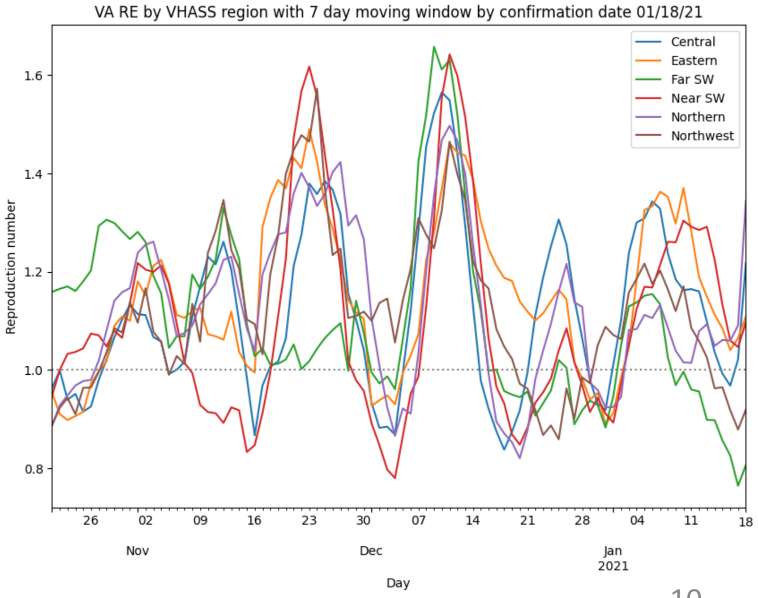
Region	Date Confirmed R_e	Date Confirmed Diff Last Week
State-wide	1.149	0.011
Central	1.218	0.053
Eastern	1.109	-0.173
Far SW	0.807	-0.154
Near SW	1.097	-0.195
Northern	1.344	0.329
Northwest	0.919	-0.166

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

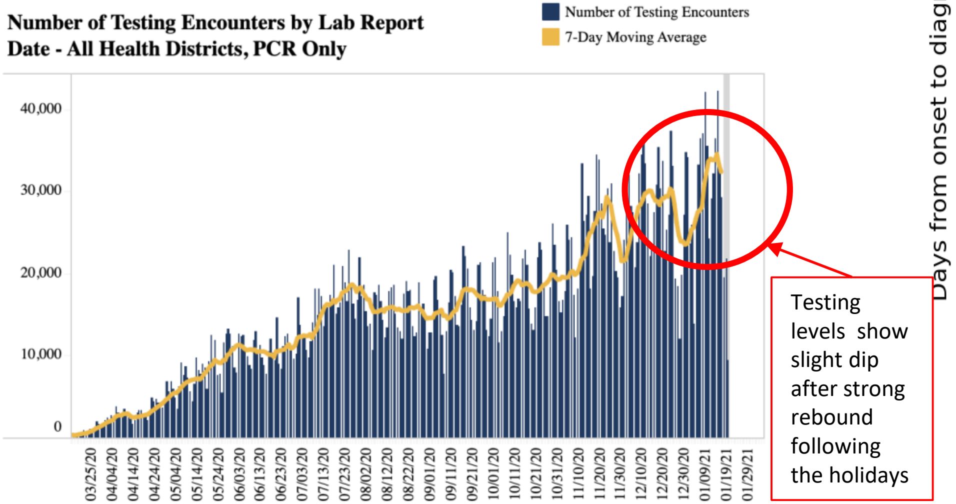
1. Anne Cori, Neil M. Ferguson, Christophe Fraser, Simon Cauchemez. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. American Journal of Epidemiology, Volume 178, Issue 9, 1 November 2013, Pages 1505–1512, https://doi.org/10.1093/aje/kwt133





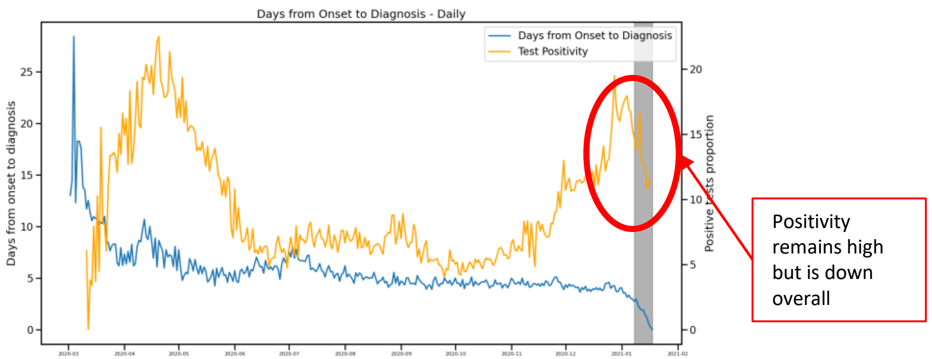
Changes in Case Detection

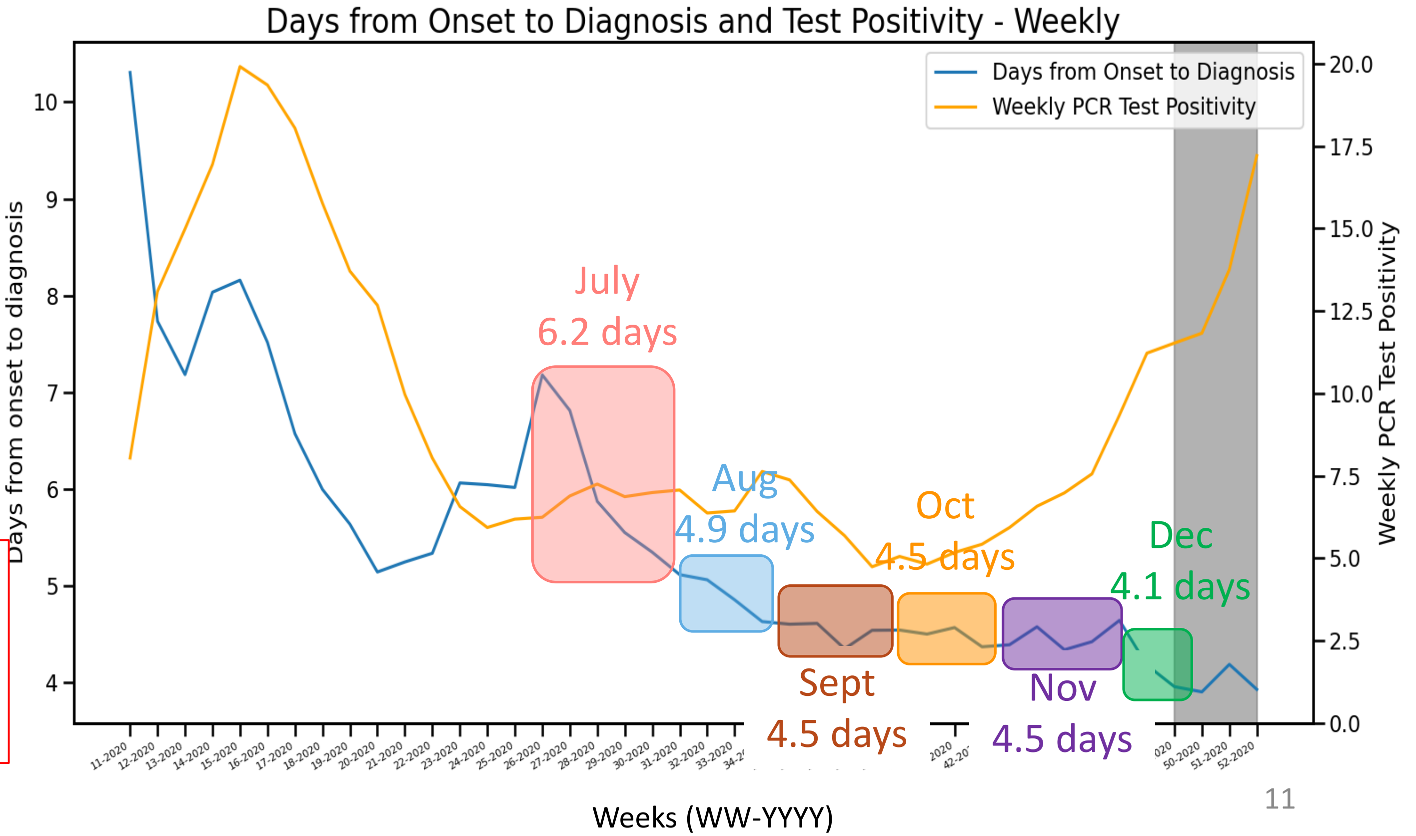
Timeframe (weeks)	Mean days	% difference from overall mean
April (13-16)	7.7	43%
May (17-21)	5.7	6%
June (22-25)	5.9	9%
July (26-30)	6.2	14%
Aug (31-34)	4.9	-9%
Sept (35-38)	4.5	-16%
Oct (39-43)	4.5	-17%
Nov (44-47)	4.5	-17%
Dec (48-49)	4.1	-25%
Overall (13-49)	5.4	--



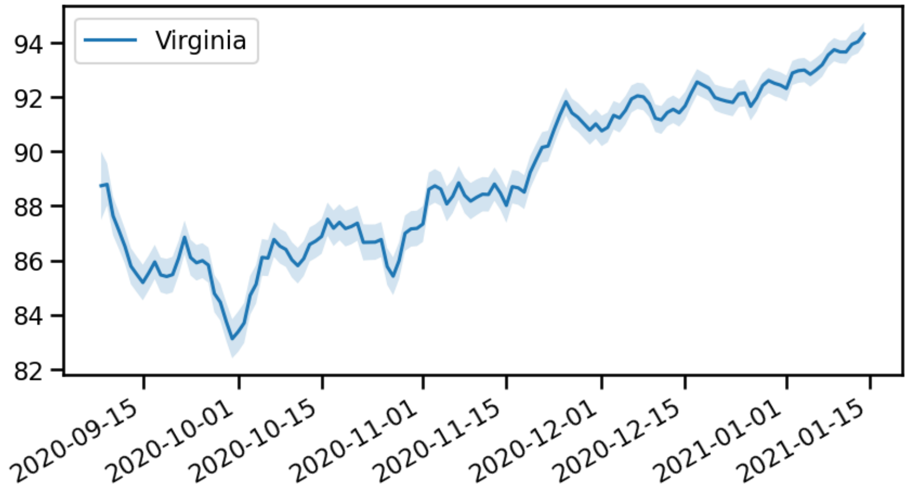
Accessed 9:00am January 20, 2021
https://www.vdh.virginia.gov/coronavirus/

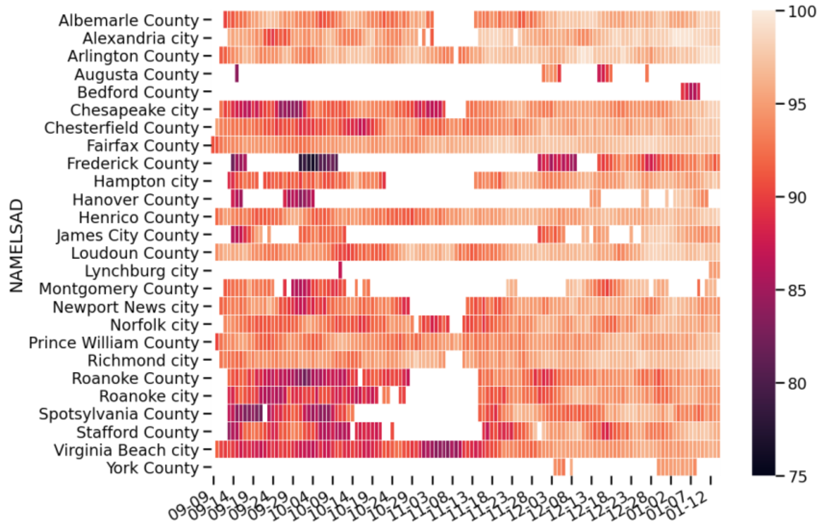
Test positivity vs. Onset to Diagnosis





Mask usage in Virginia



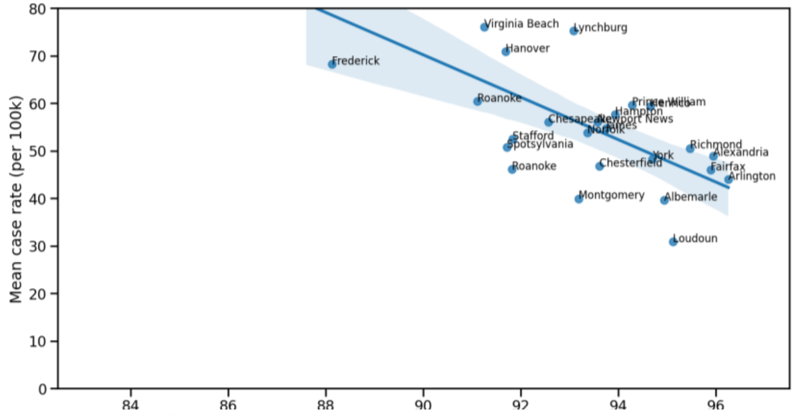


Some county level fluctuations since beginning of Sept., though data quality may be affected by sample sizes

State level mask usage as reported via Facebook surveys has shown steady increase over past three months

- ~88% (early Nov) to ~94% (mid Jan)
- Some variance across the commonwealth
- ~3000 daily responses from VA

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



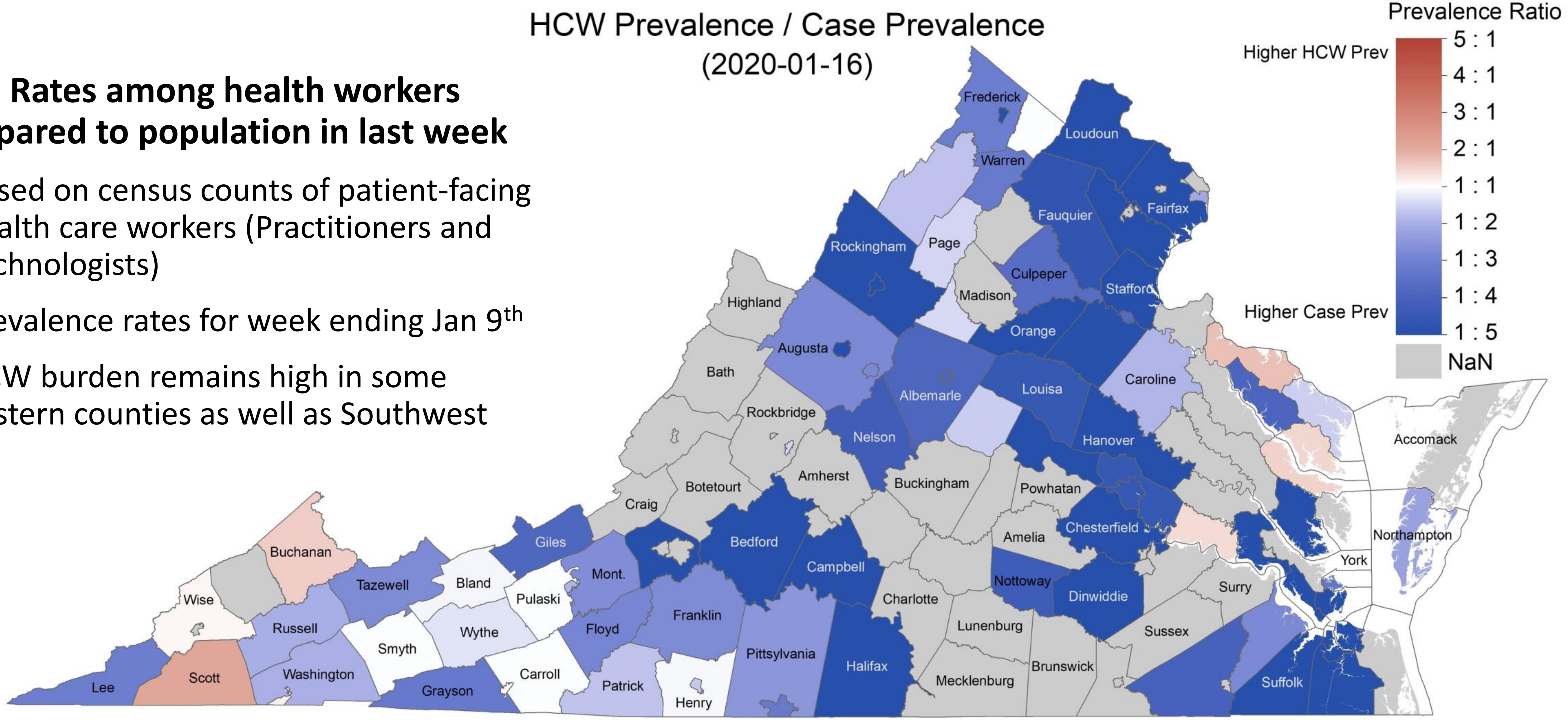
Correlations seen among VA counties between mask use and case rate are now stronger due to surging growth

Slope: - 4.5; for every % we see a ~4.5/100K case rate difference

Health Care Worker Prevalence (per 100K)

Case Rates among health workers compared to population in last week

- Based on census counts of patient-facing health care workers (Practitioners and Technologists)
- Prevalence rates for week ending Jan 9th
- HCW burden remains high in some Eastern counties as well as Southwest



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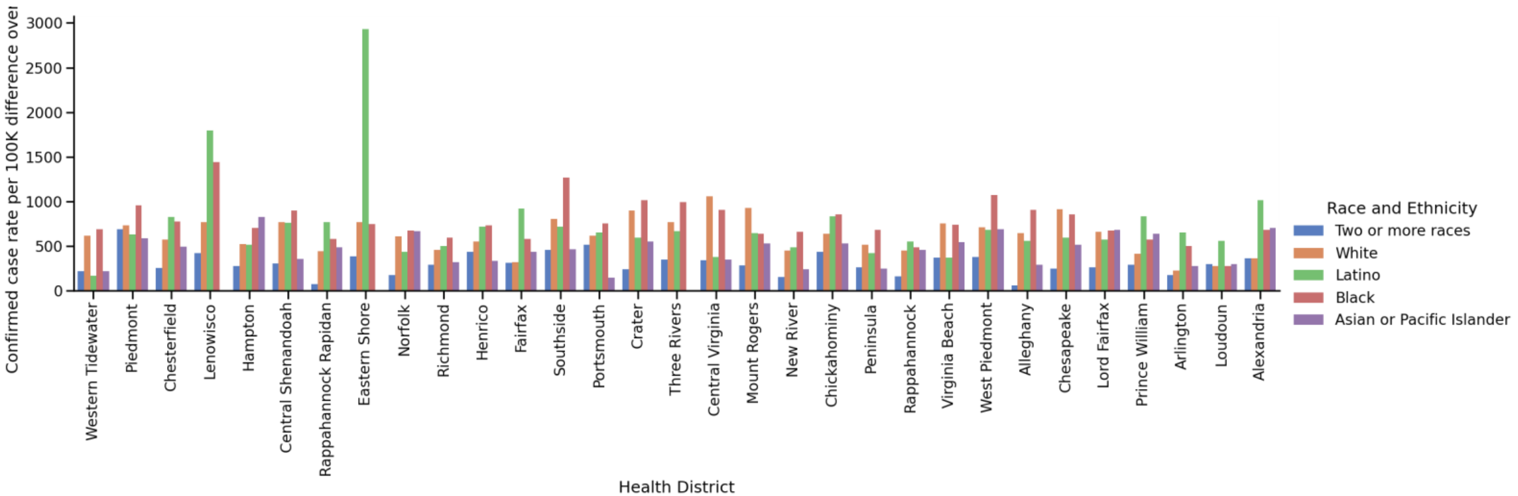
Race and Ethnicity – Recent Rate Changes (per 100K)

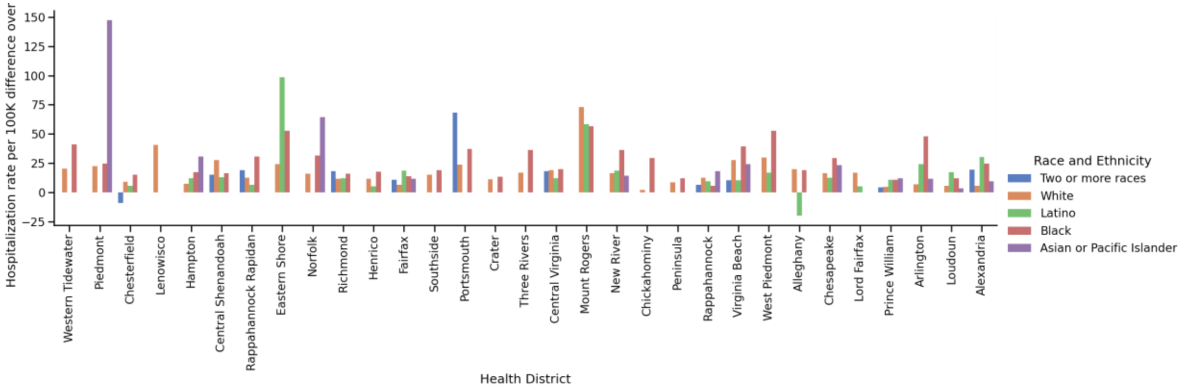
Recent Changes in Race and Ethnicity Rates (per 100k)

- 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

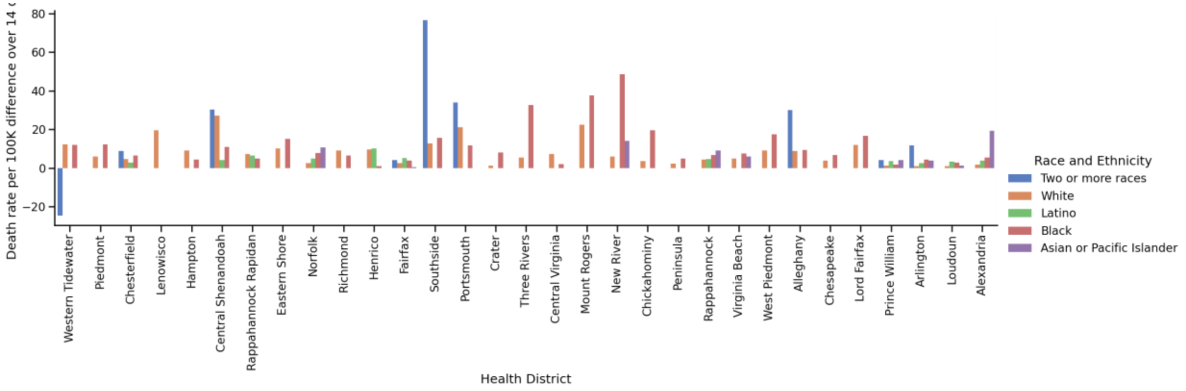
Case Rate



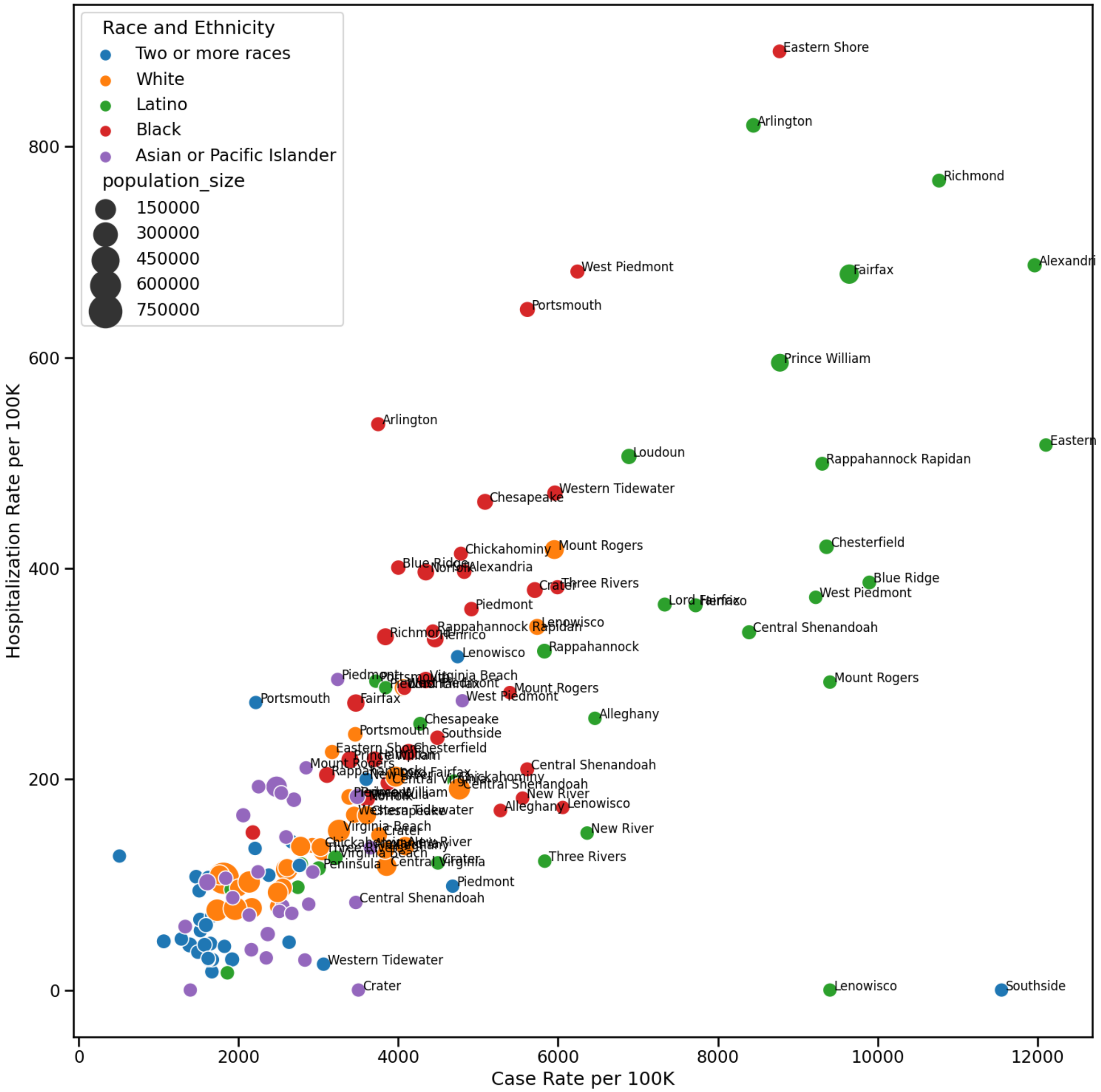
Hospitalization Rate



Death Rate



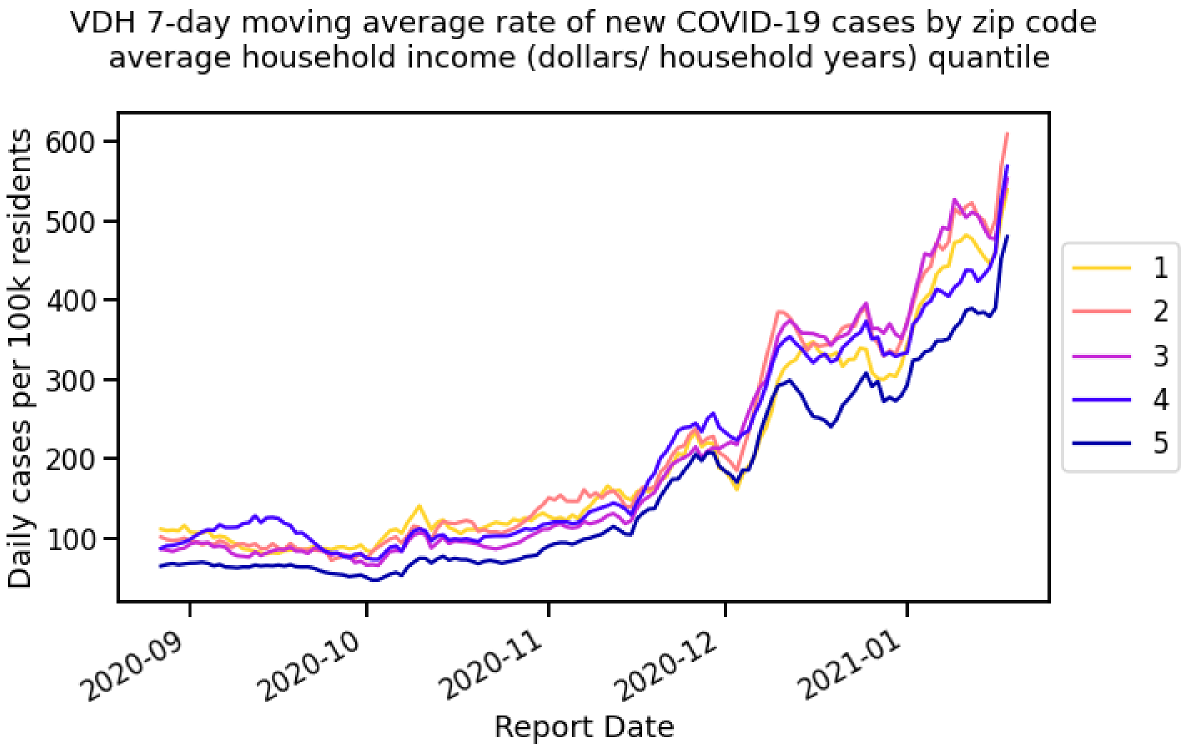
Race and Ethnicity cases per 100K



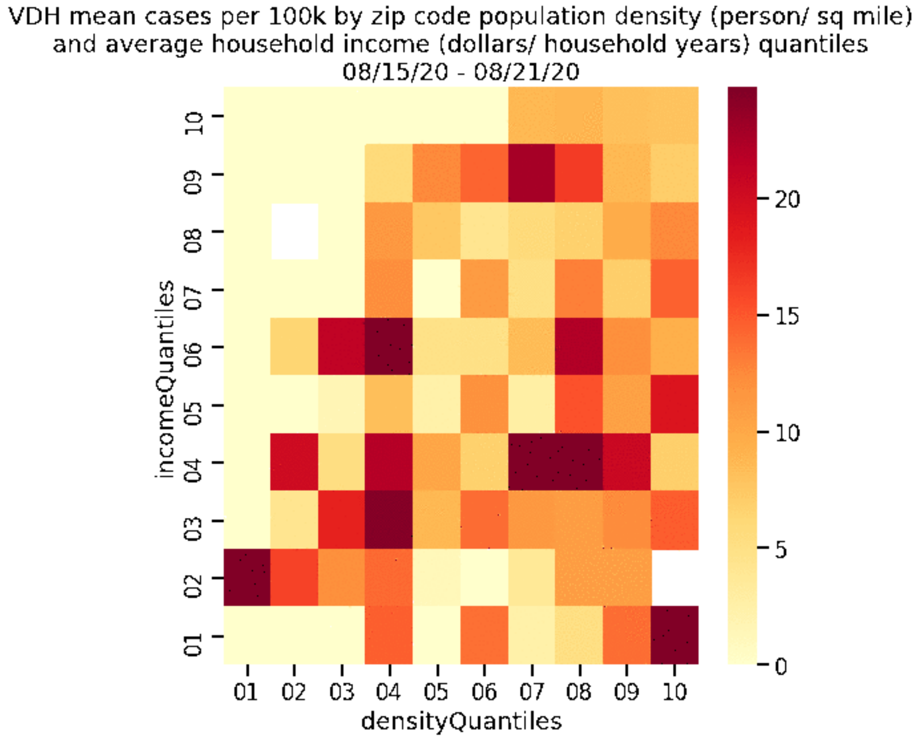
Rates per 100K of each Racial-Ethnic population by Health District

- 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



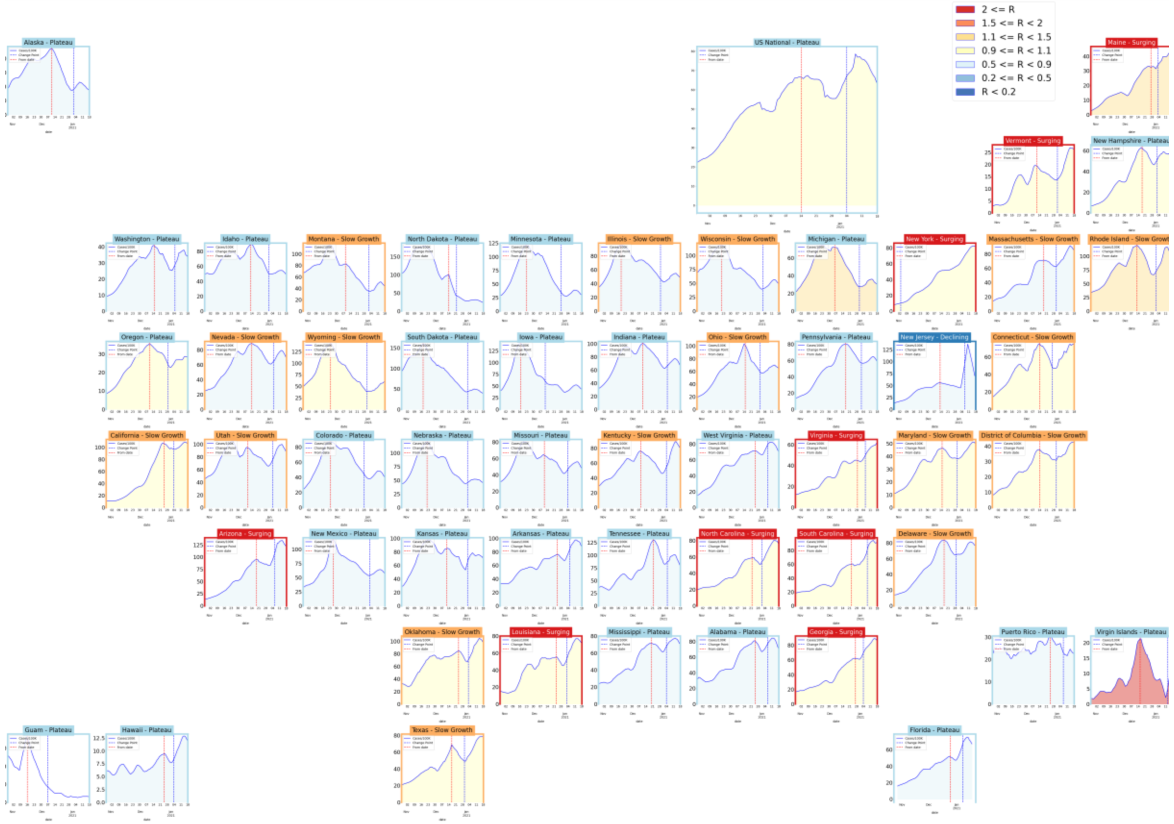
All zip codes show back into growth, wealthiest zip code now lags the rest significantly



Full evolution of pandemic, shows shifts from denser and wealthier zip codes to poorer and less dense zip codes

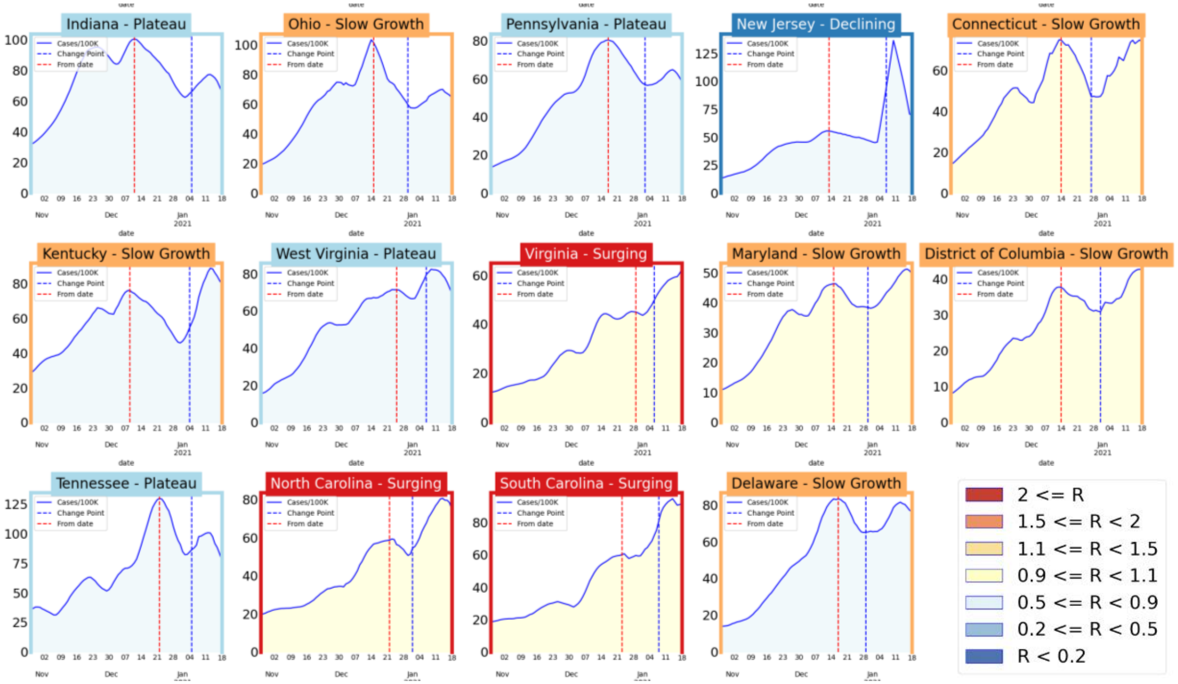
Other State Comparisons

Trajectories of States



- After a short rebound most states are plateauing (27) or slowly growing (17)

Virginia and her neighbors



- VA continues to surge along with 8 other states
- VA and her neighbors are relatively active compared to the rest of the US

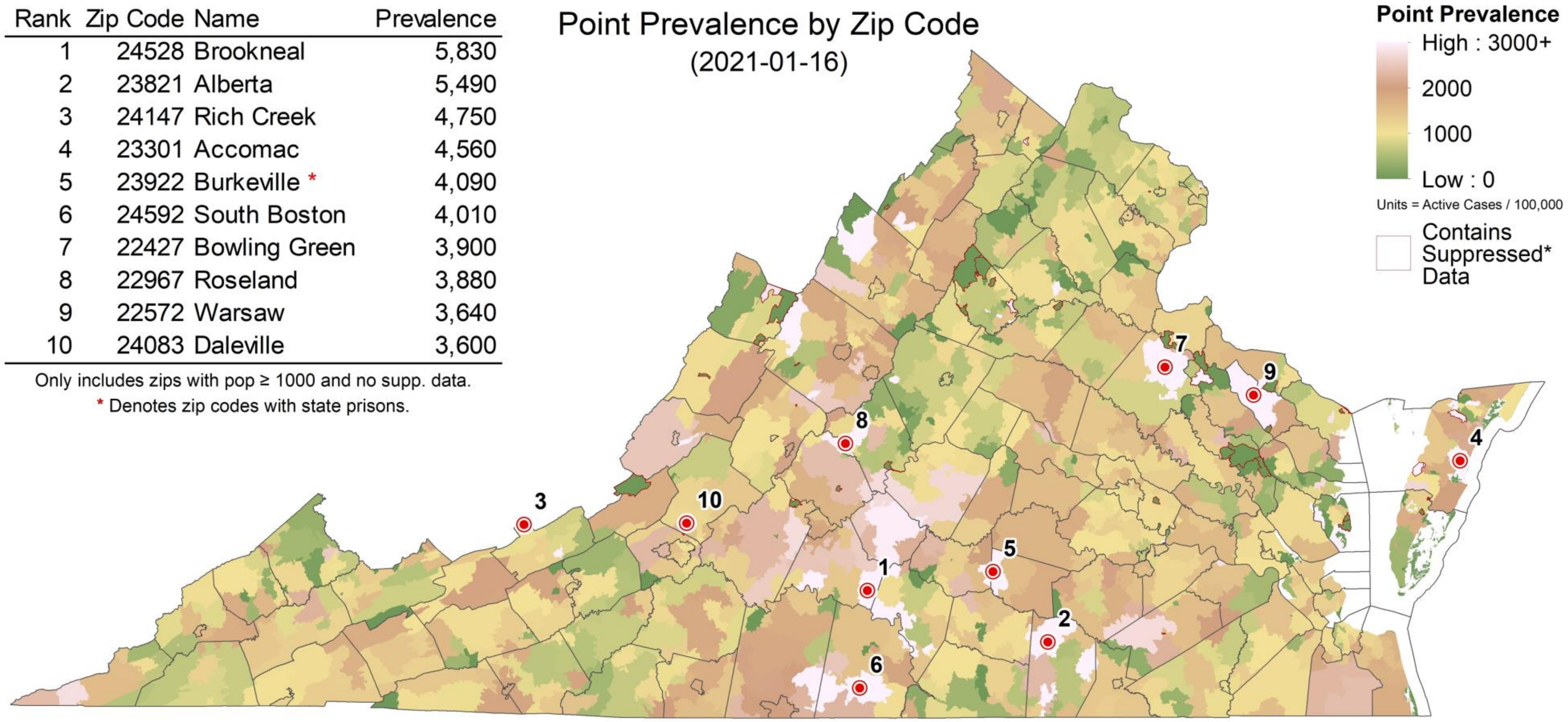
Zip code level weekly Case Rate (per 100K)

Case Rates in the last week by zip code

- Fewer prisons are in the top ten, most prisons seem to have intense rates for 2 to 3 weeks
- Some counts are low and suppressed to protect anonymity, those are shown in white

Rank	Zip Code	Name	Prevalence
1	24528	Brookneal	5,830
2	23821	Alberta	5,490
3	24147	Rich Creek	4,750
4	23301	Accomac	4,560
5	23922	Burkeville *	4,090
6	24592	South Boston	4,010
7	22427	Bowling Green	3,900
8	22967	Roseland	3,880
9	22572	Warsaw	3,640
10	24083	Daleville	3,600

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



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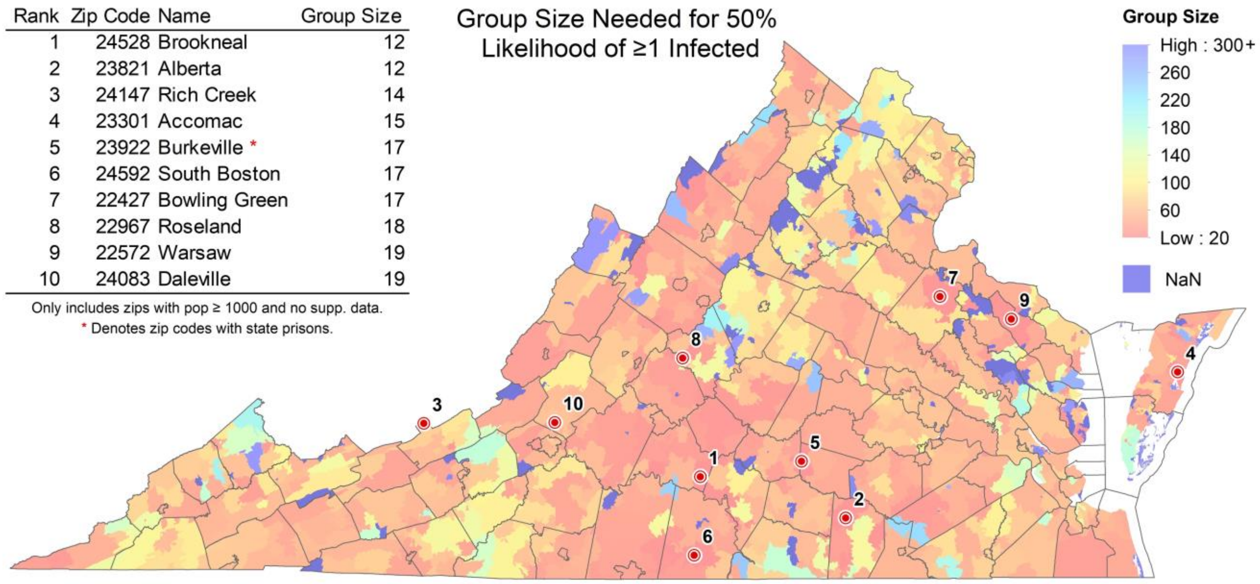
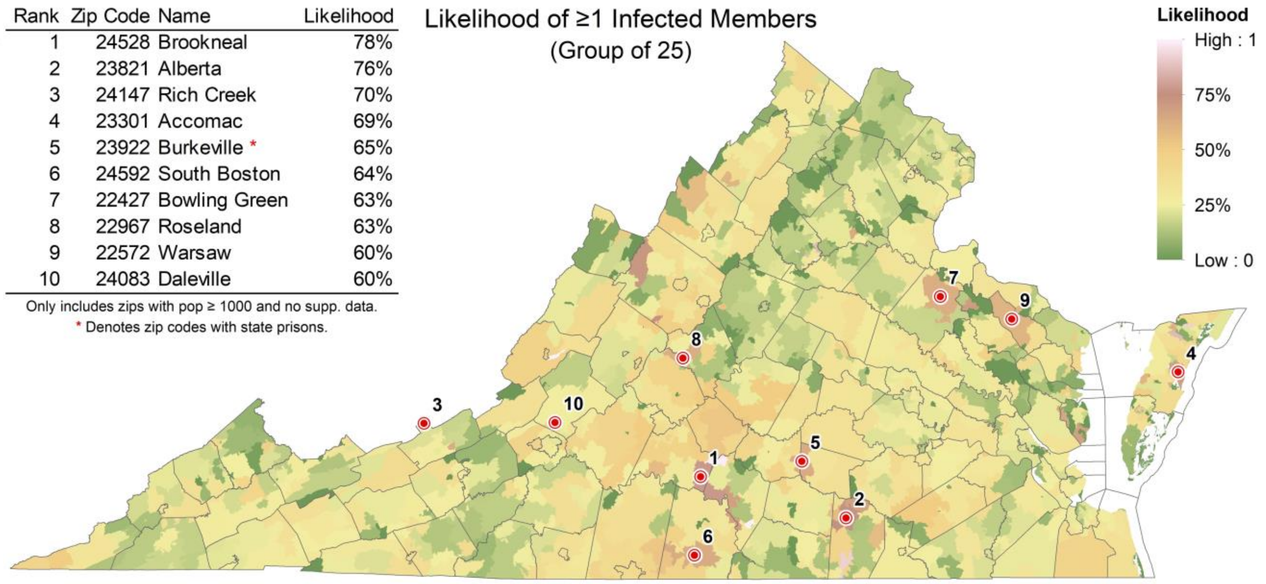
Risk of Exposure by Group Size

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



Based on zip code point prevelence for week ending 2021-01-16

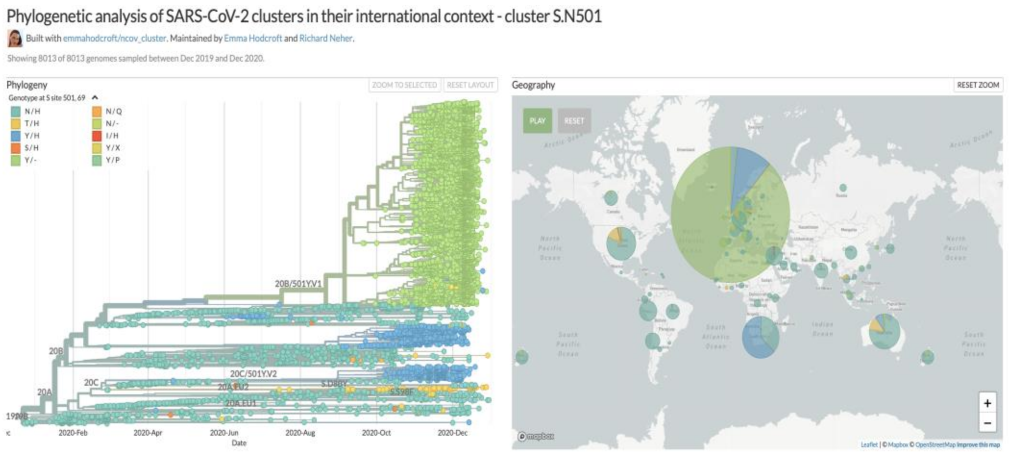


Based on zip code point prevelence for week ending 2021-01-16

New variants of SARS-CoV2

Emerging new variants with increased transmissibility still no evidence of higher severity

- Evolution expected when virus under selective pressure



nextstrain.org

Variant VUI 202012/01 aka Lineage B.1.1.7

- B.1.1.7 has been detected in at least 122 cases in 20 states
- Given observed growth rate in UK and Denmark, estimate it will predominate in the US by mid-March

Variant 501Y.V2 aka Lineage B.1.351

- Emerging strain in South Africa is also of concern for vaccine escape
- Experiments have demonstrated reduced potency of convalescent sera and monoclonal antibodies

New lineage in Brazil P.1 (similar mutations as in B.1.1.7 and B.1.351)

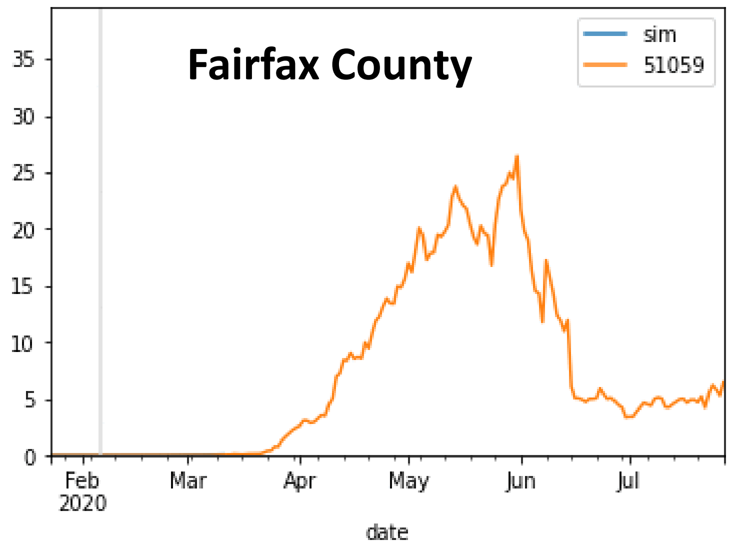
- Emerging strain in the Amazon also shows potential of escaping existing immunity
- Resurgence of hospitalizations in Manaus, Brazil despite estimated ¾ of the population infected

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

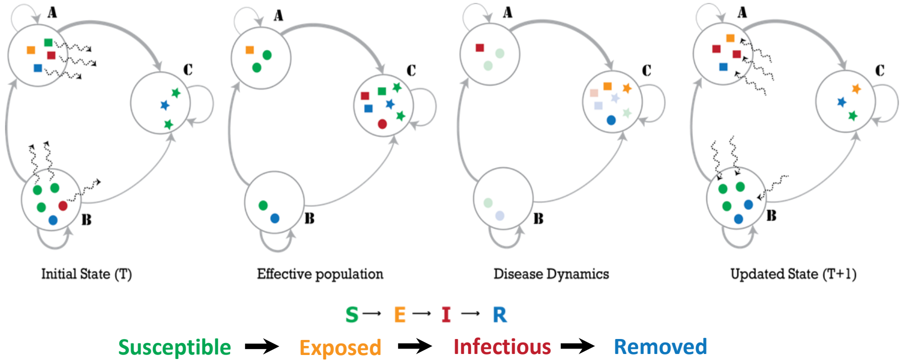


Model: An alternative use of the same meta-population model, PatchSim

- 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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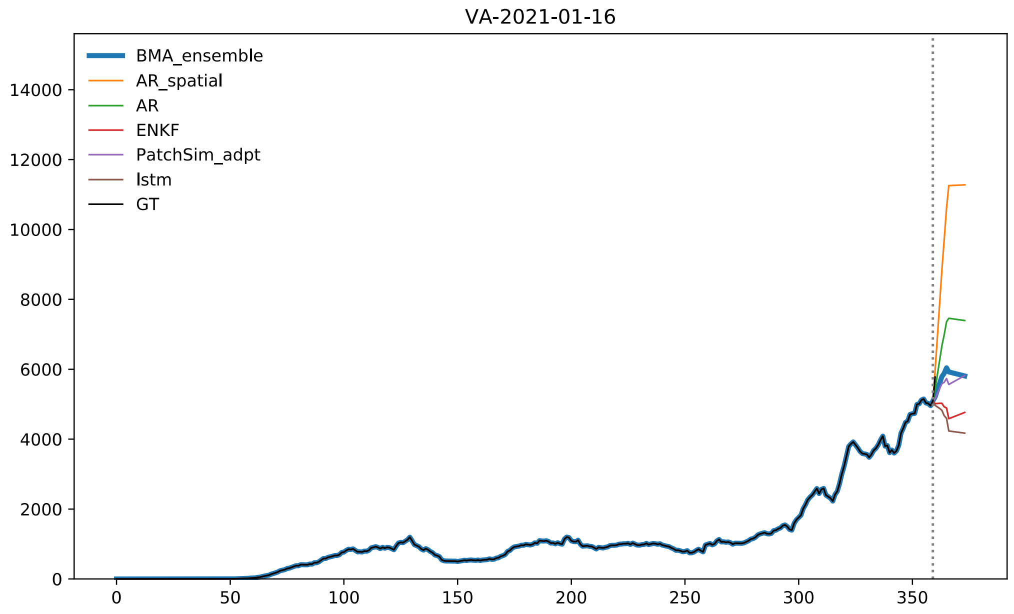
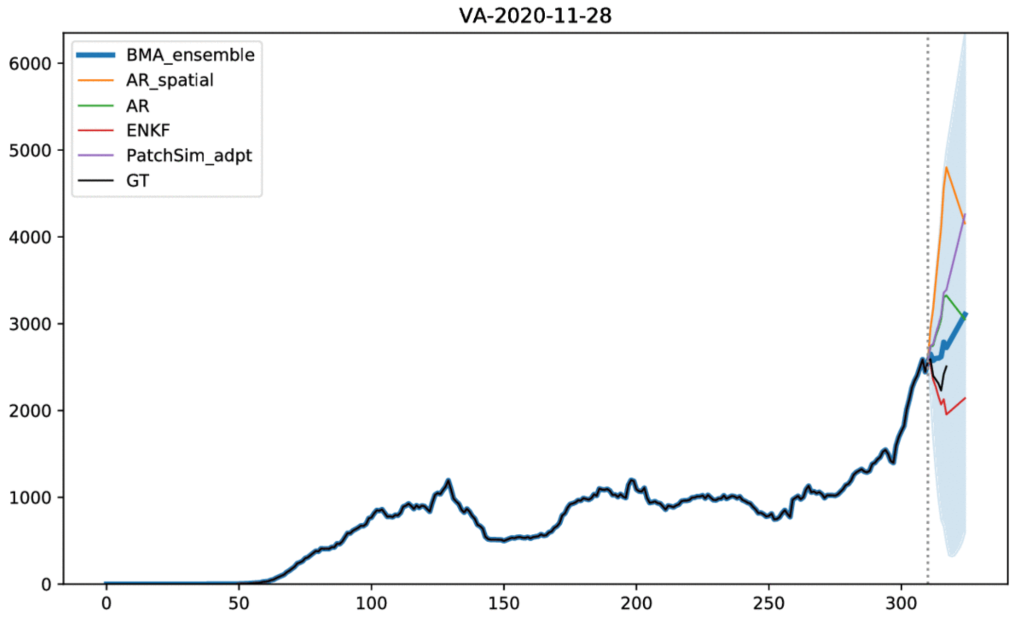
Using Ensemble Model to Guide Projections

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





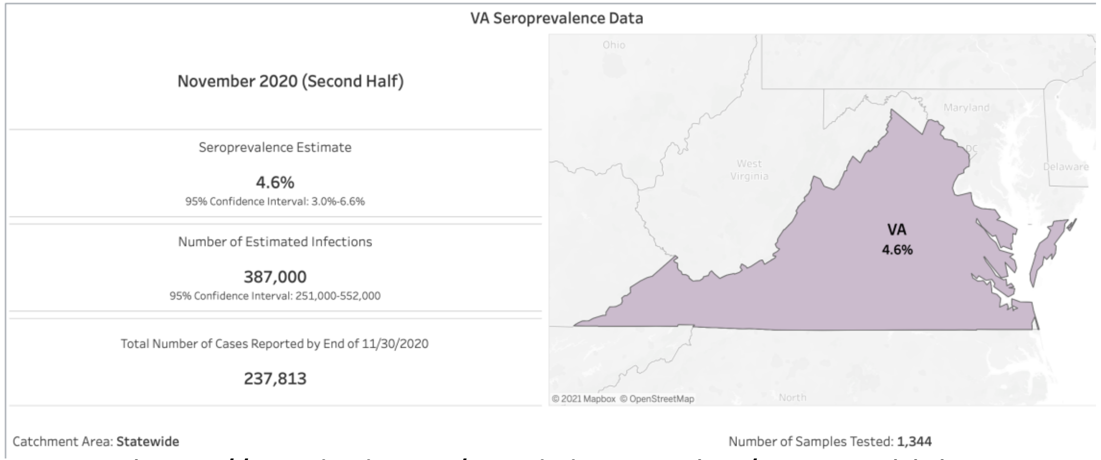
Seroprevalence updates to model design

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 4.6% [3.0% – 6.6%] seroprevalence as of Nov 12th – 26th up from 4.1% 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)



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

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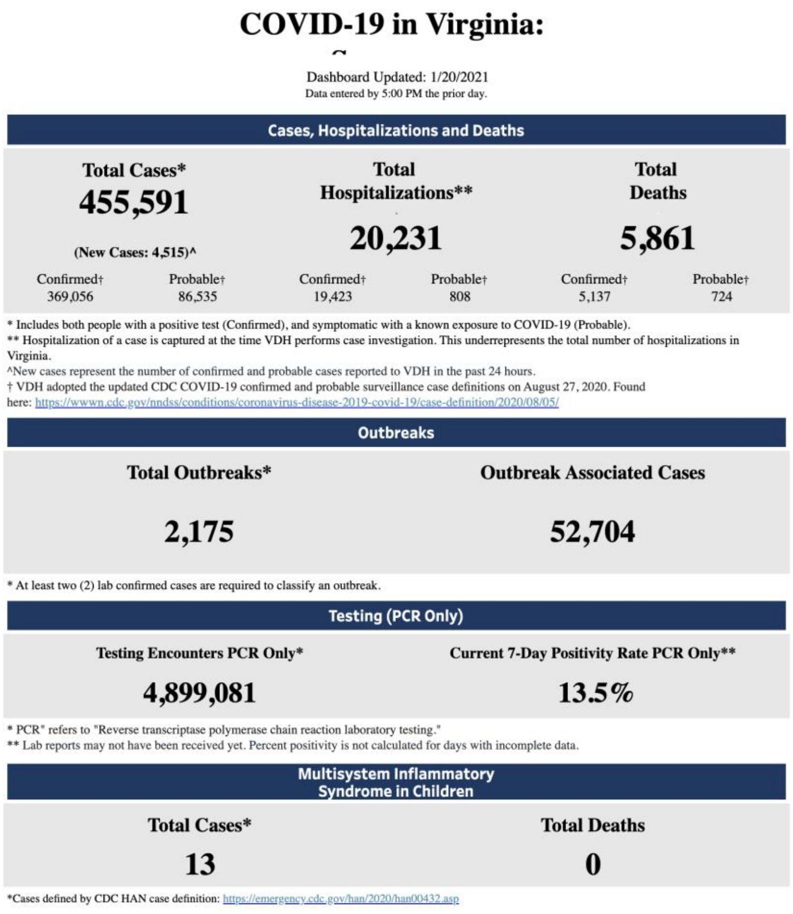
Calibration Approach

- **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: 1/20/2021
Data entered by 5:00 PM the prior day.

Cases, Hospitalizations and Deaths

Total Cases*		Total Hospitalizations**		Total Deaths	
455,591		20,231		5,861	
(New Cases: 4,515)^					
Confirmed†	Probable†	Confirmed†	Probable†	Confirmed†	Probable†
369,056	86,535	19,423	808	5,137	724

* Includes both people with a positive test (Confirmed), and symptomatic with a known exposure to COVID-19 (Probable).
** Hospitalization of a case is captured at the time VDH performs case investigation. 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/

Outbreaks

Total Outbreaks*	Outbreak Associated Cases
2,175	52,704

* 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**
4,899,081	13.5%

* 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 9:00am January 20, 2021

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

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Scenarios – Seasonal Effects

- Variety of factors continue to drive transmission rates
  - Seasonal impact of weather patterns, travel and gatherings related to holidays, fatigue with infection control practices
- Plausible levels of transmission can be bounded by past experience
  - Assess transmission levels at the county level since May 2020
  - Use the highest and lowest levels experienced (excluding outliers) as plausible bounds for levels of control achievable
  - Transition from current levels of projection to the new levels over 2 months
- New planning Scenarios:
  - **Best of the Past**: Lowest level of transmission (10^{th} percentile)
  - **Fatigued Control**: Highest level of transmission (95^{th} percentile) increased by additional 5%

Scenarios – Novel Variants

- Several novel variants of SARS-CoV2 are being tracked
  - Some are more transmissible, some may escape immunity from previous natural infection and/or vaccination, others may be more severe
- New Variant B.1.1.7 is best understood and is in US
  - Several different studies have estimated the increase in transmission to be 30-55%, we use 40% increase from the current baseline projection
  - Gradually replace the current transmissibility with the augmented transmissibility over the course of 2 months as estimated by a recent MMWR report from CDC
- Additional planning Scenarios:
  - **NewVariants**: Current projected transmissibility increases gradually over 2 months to level 40% more transmissible

Scenarios – Vaccines

- Vaccination has started, and efforts are underway to increase its pace
  - Exact achievable rollouts and level of coverage are unknown
- Vaccine efficacy varies over course of vaccine
  - FDA EUAs show 50% efficacy achieved 2 weeks after first dose, and 95% two weeks after second dose
  - Assuming 3.5 week (average of Pfizer and Moderna) gap between doses
- Schedules
  - **Optimistic**: 25M courses in US (~ 660K in VA) starting in January, and continued 25M (~660K) per month
  - **Pessimistic**: 12.5M people in US (~330K in VA) in January, then 25M (~660K) per month, with vaccine hesitancy leaving 50% of delivered vaccines unused
  - Assume that vaccinations before January protect individuals but are not influencing transmission dynamics

Current rollouts and scenarios inspired by MIDAS Network COVID-19 Scenario Hub: https://github.com/midas-network/covid19-scenario-modeling-hub

Scenarios – Seasonal Effects and Vaccines

Three scenarios combine these seasonal effects and vaccine scenarios

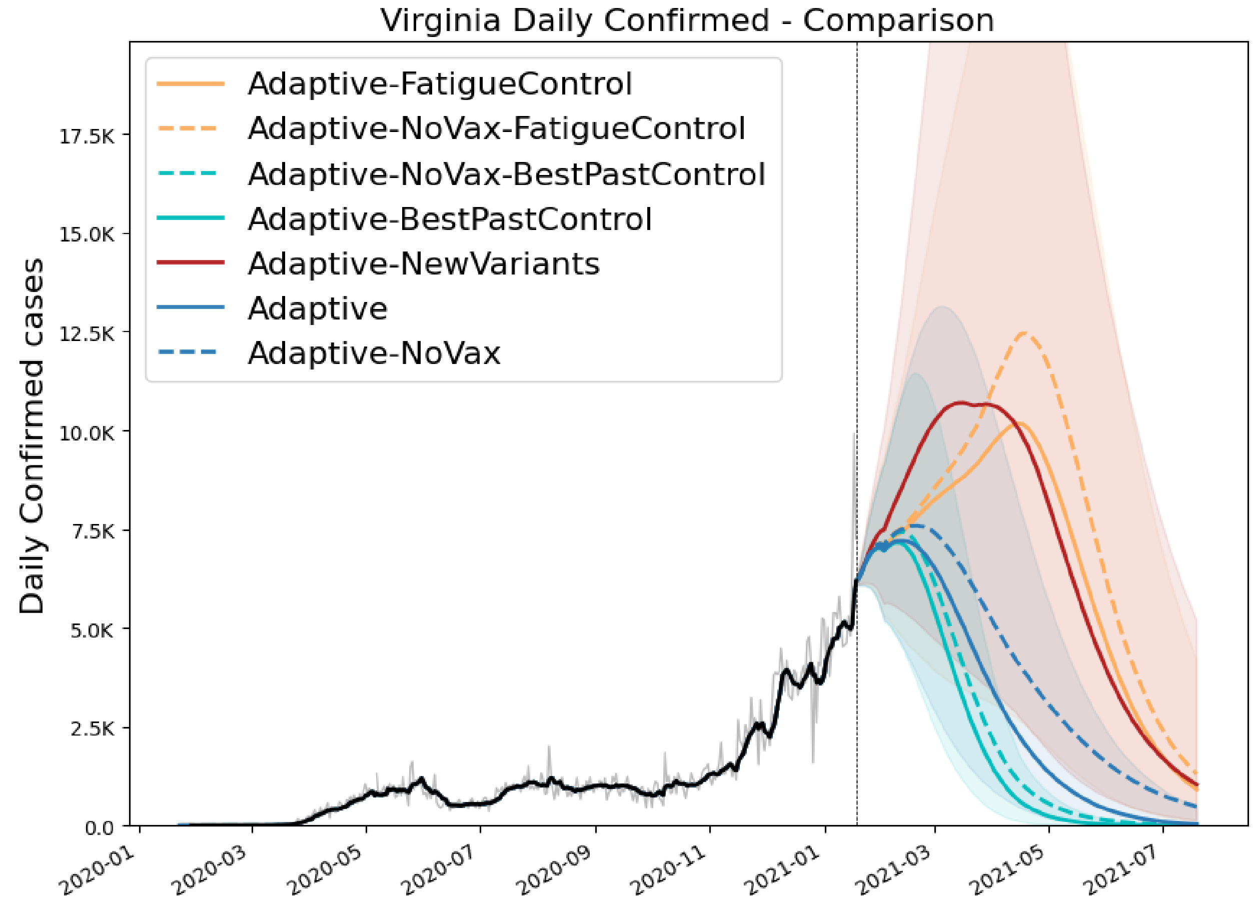
- **Adaptive**: No seasonal effects from base projection paired with optimistic vaccine schedule
- **Adaptive-FatigueControl**: Fatigued control seasonal effects paired with pessimistic vaccine schedule
- **Adaptive-BestPastControl**: Best of the past control seasonal effects paired with optimistic vaccine schedule
- **Adaptive-NewVariants**: Boosting of transmissibility over next 2 months from their emergence and eventual ubiquity uses optimistic vaccine schedule

- Counterfactuals with no vaccine ("NoVax") are provided for comparison purposes

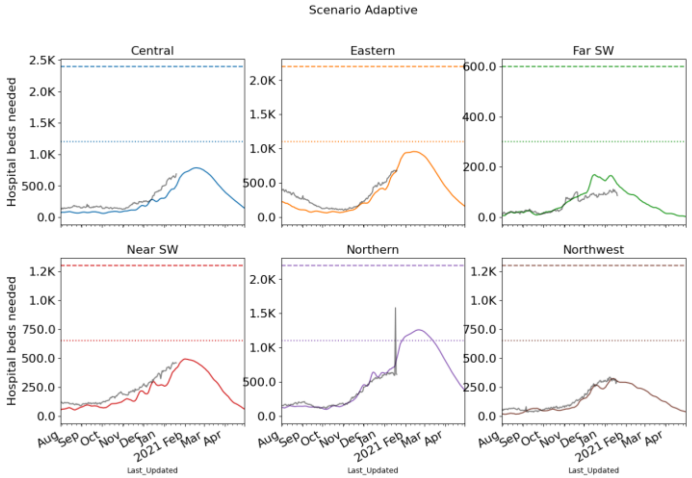
Model Results

Outcome Projections

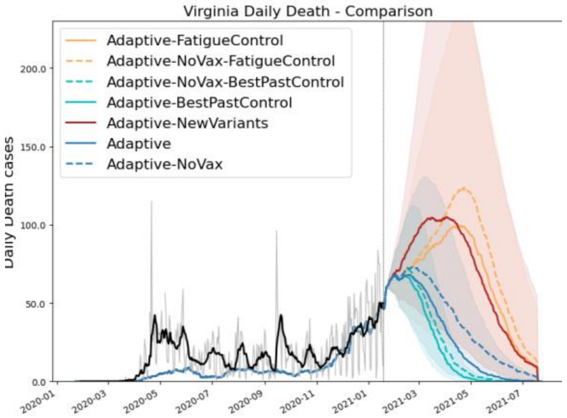
Confirmed cases



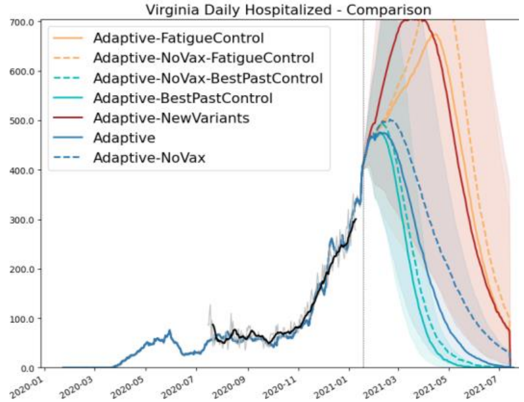
Estimated Hospital Occupancy



Daily Deaths



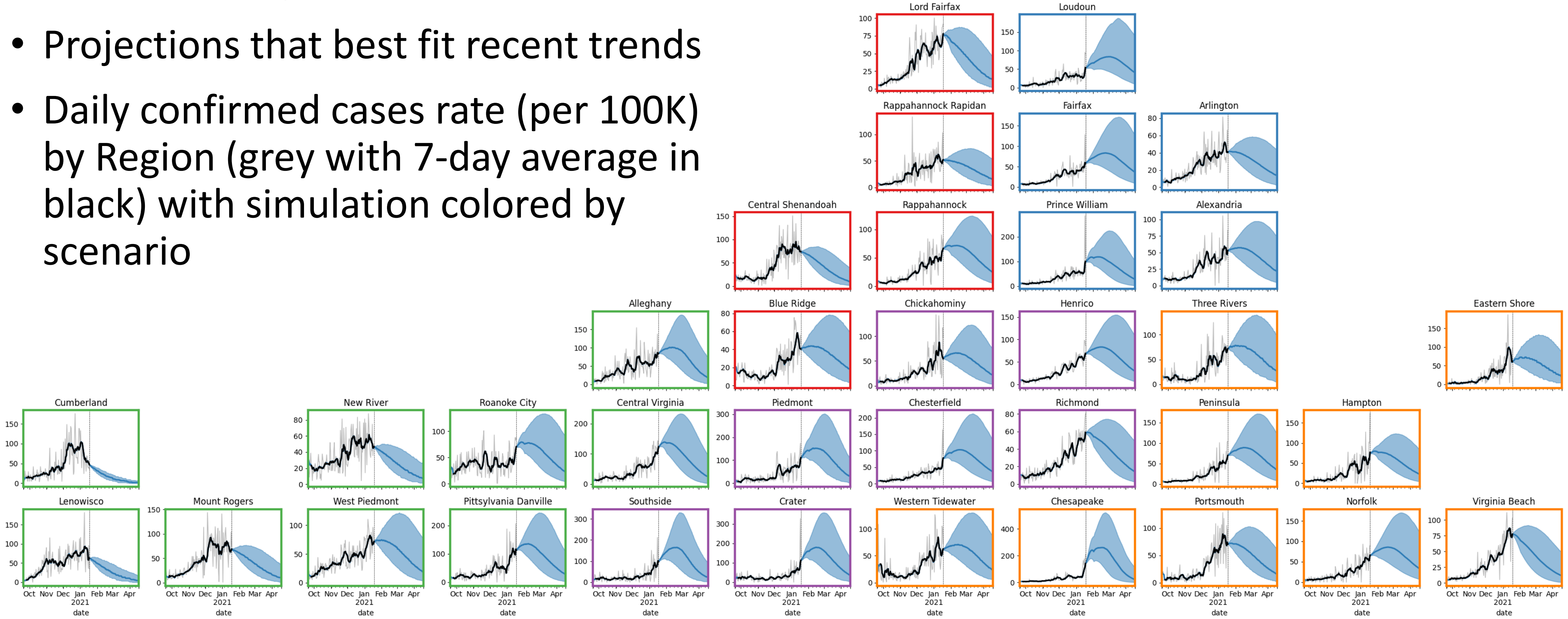
Daily Hospitalized



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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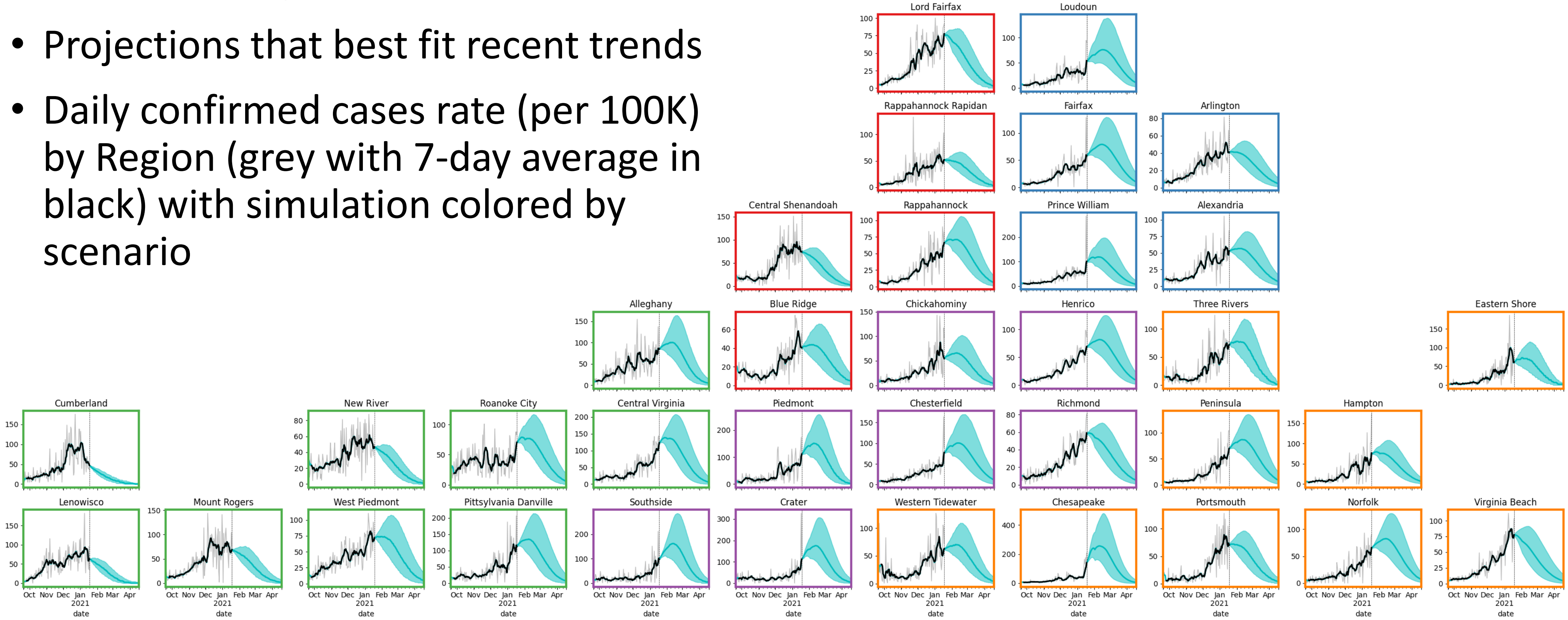
District Level Projections: Adaptive-BestPastControl

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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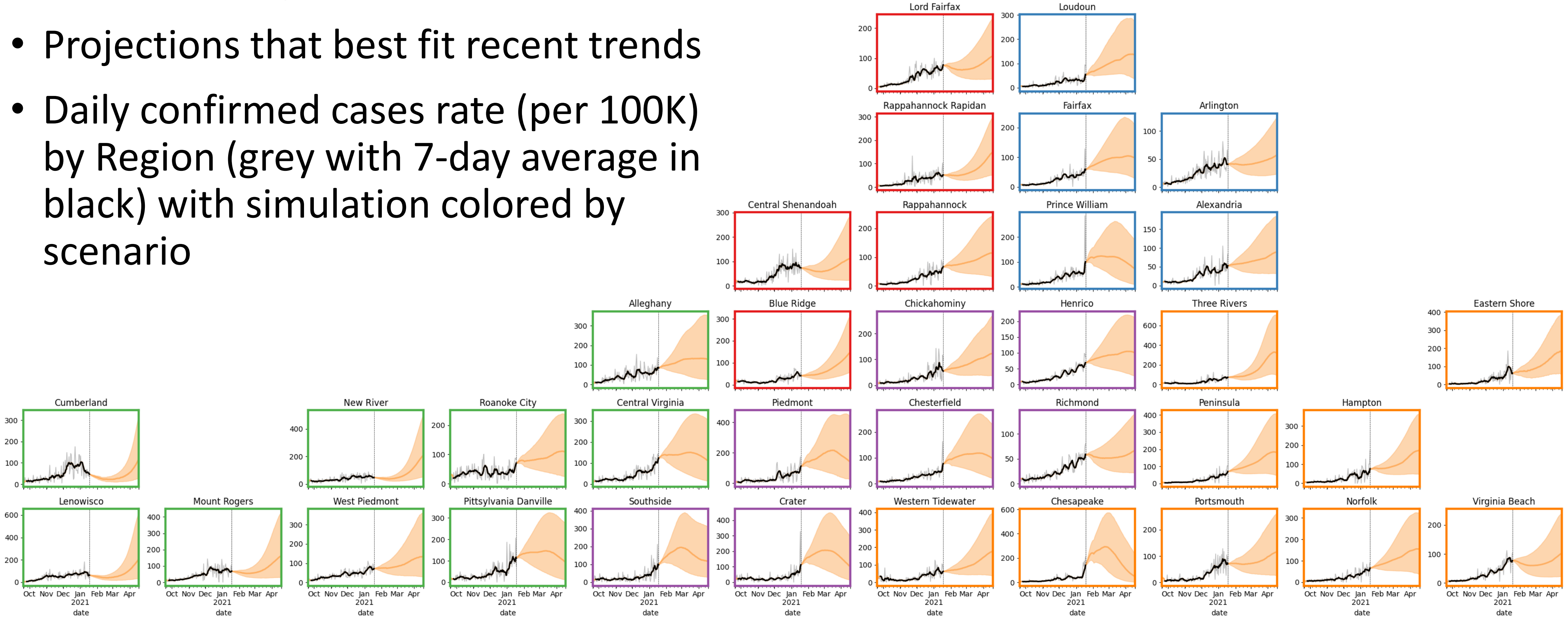
District Level Projections: Adaptive-FatigueControl

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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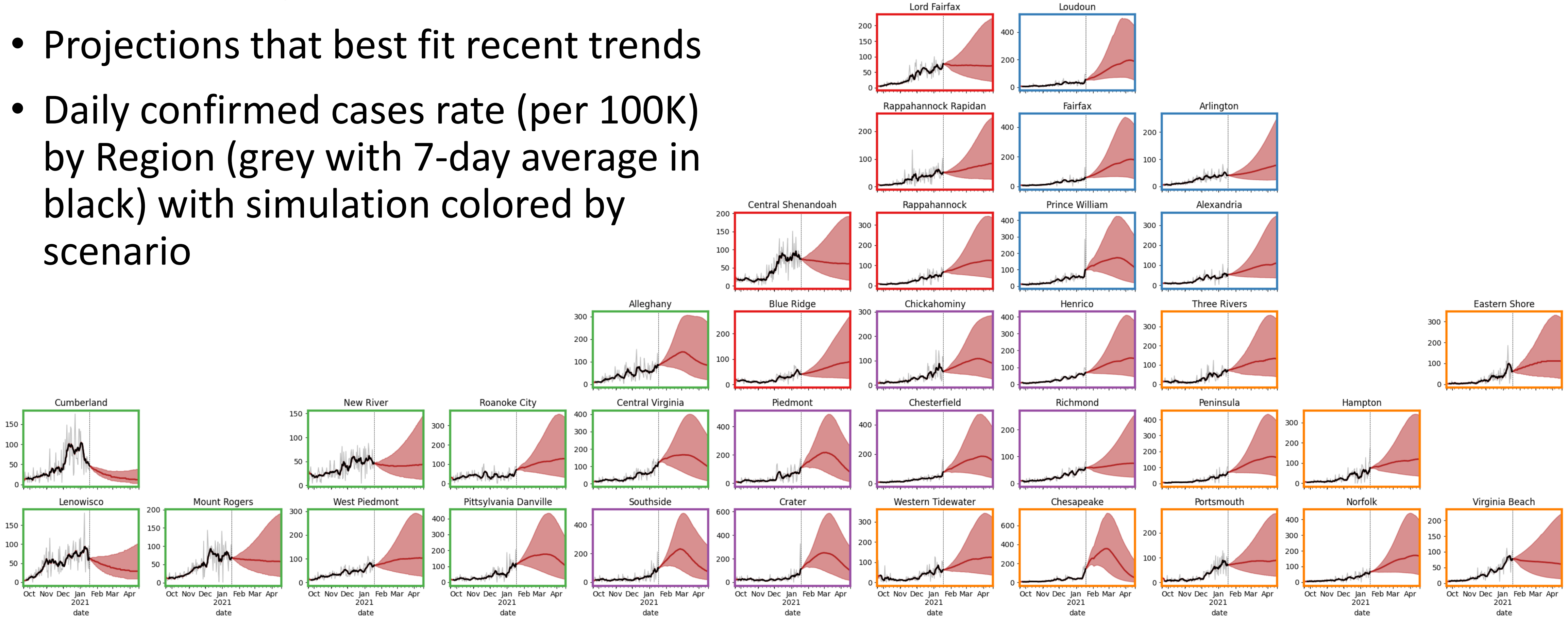
District Level Projections: Adaptive-NewVariants

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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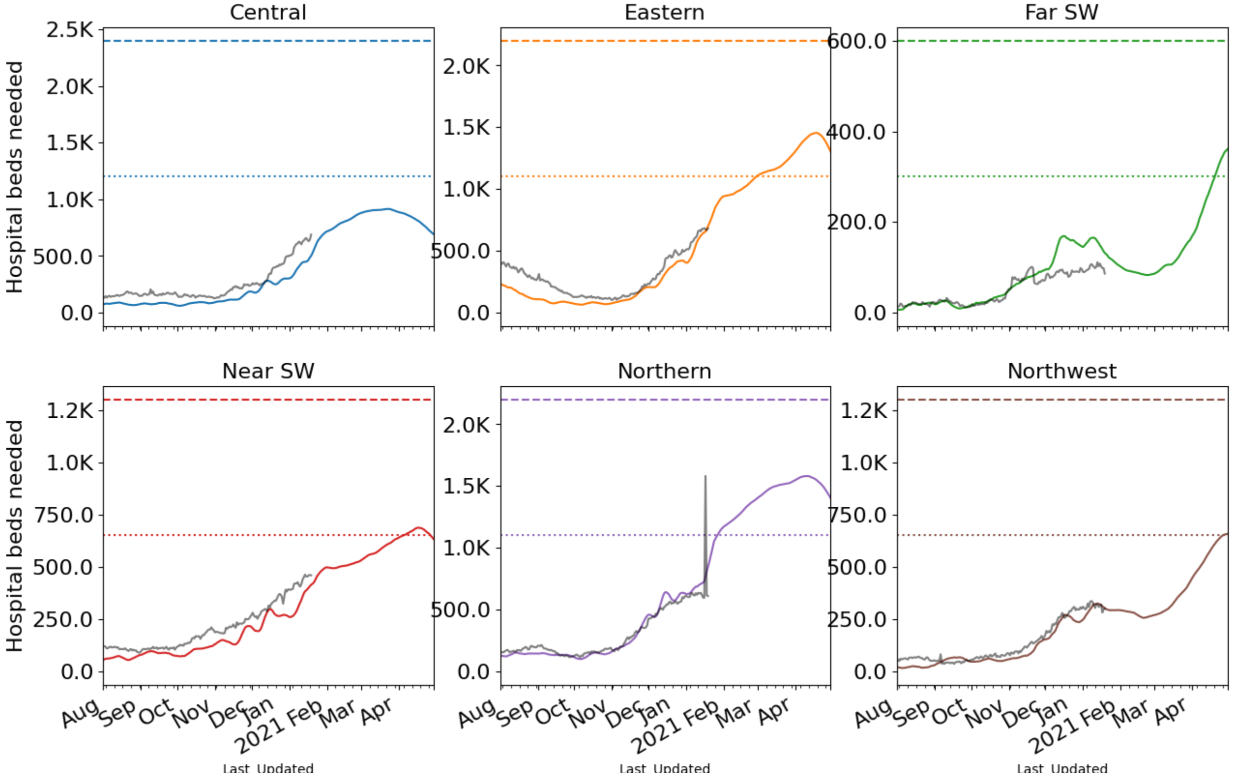
Hospital Demand and Bed Capacity by Region

Capacities* by Region – Adaptive-FatigueControl

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



Week Ending	Adaptive	Adaptive-FatigueControl
1/17/21	36,210	36,210
1/24/21	45,021	45,046
1/31/21	48,766	48,977
2/7/21	49,496	50,130
2/14/21	50,370	51,943
2/21/21	49,712	54,097
2/28/21	47,466	56,475
3/7/21	43,800	58,501
3/14/21	39,136	60,354
3/21/21	34,080	62,208
3/28/21	28,881	64,617
4/4/21	24,068	67,530

Weekly confirmed cases

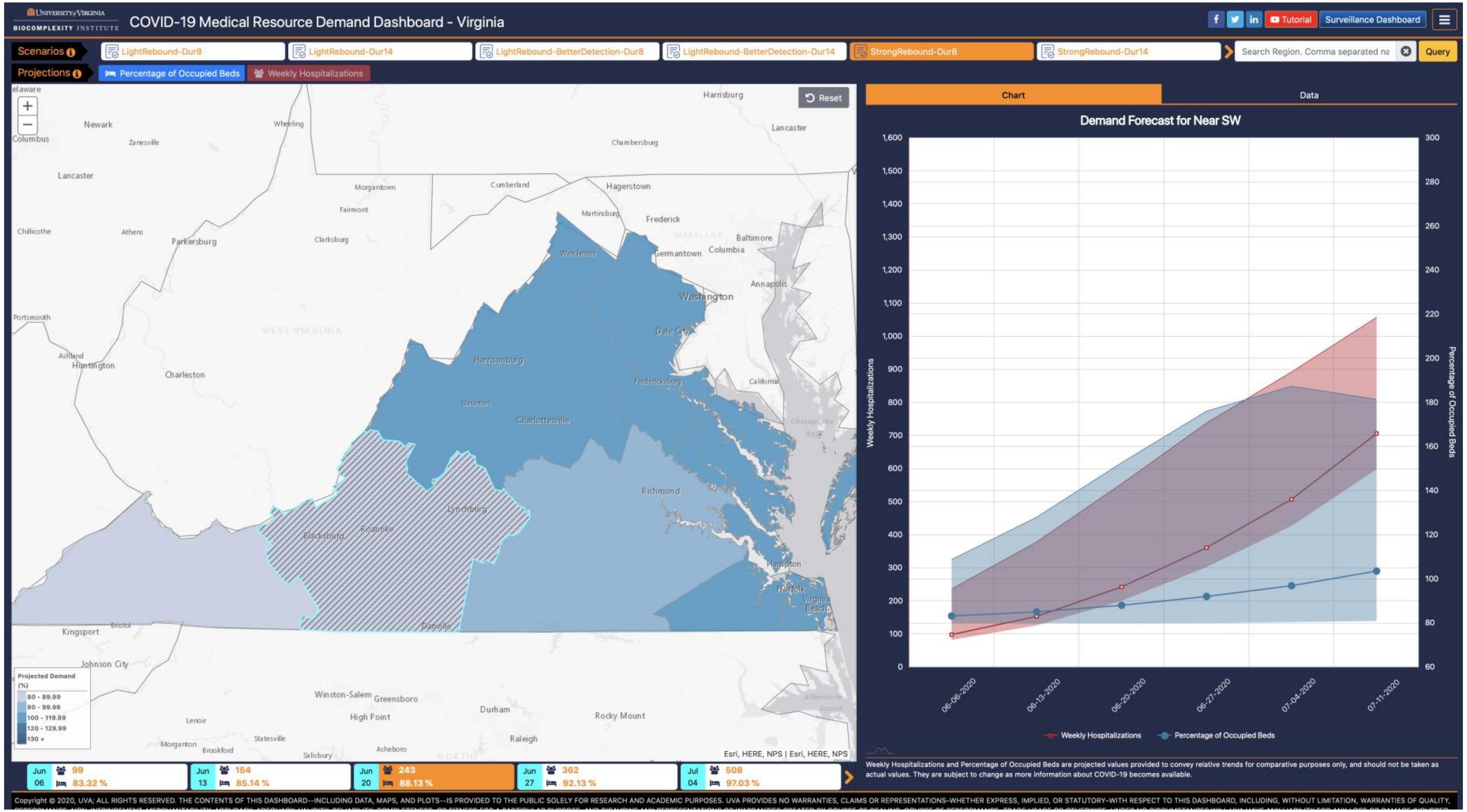
If Adaptive-FatigueControl scenario persists:

- All regions approach or surpas initial bed capacity this winter
- Surge bed capacity is unlikely to be reached in coming 4 months

* Assumes average length of stay of 8 days

Medical Resource Demand Dashboard

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



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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 continues to surge with some signs of slowing as national levels subside**
- VA mean weekly incidence up to 72/100K from 60/100K, as national levels decline (to 54/100K from 67/100K); Virginia records highest daily case rate in past week (116/100K on Jan 17th) and weekly average is above national average
- Projections are mixed across commonwealth with overall short-term growth at state level
- Recent updates:
  - Modified scenarios to be based on past control levels (best and fatigued)
  - Added a scenario based on emerging new variants with enhanced transmissibility
  - Refined vaccination schedule to account for partial protection from first dose and merged with current vaccines administered to date
- 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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NSSAC. PatchSim: Code for simulating the metapopulation SEIR model. https://github.com/NSSAC/PatchSim (Accessed on 04/10/2020).

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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

Estimating Daily Reproductive Number

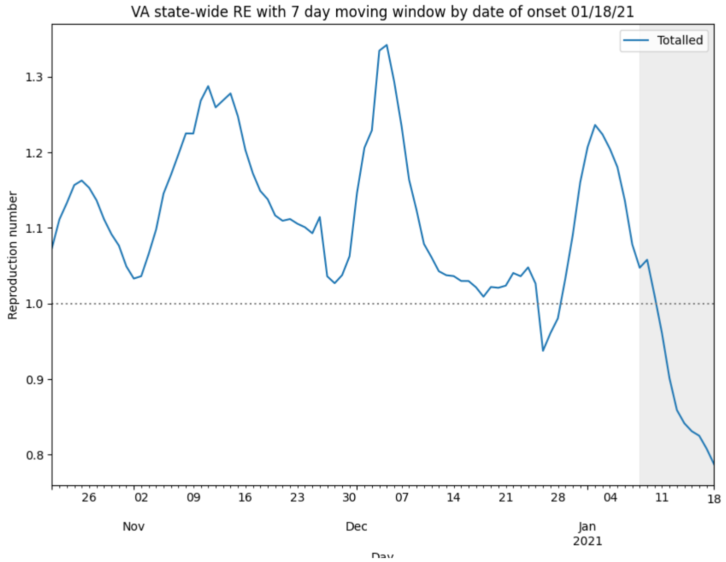
Jan 9th Estimates

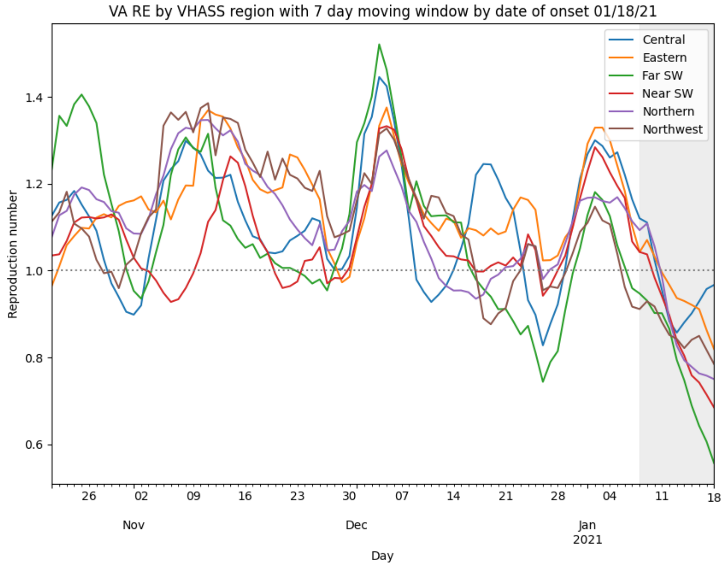
Region	Date of Onset R_e	Date Onset Diff Last Week
State-wide	1.058	-0.109
Central	1.111	-0.131
Eastern	1.070	-0.186
Far SW	0.931	-0.219
Near SW	1.037	-0.192
Northern	1.108	0.021
Northwest	0.929	-0.147

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

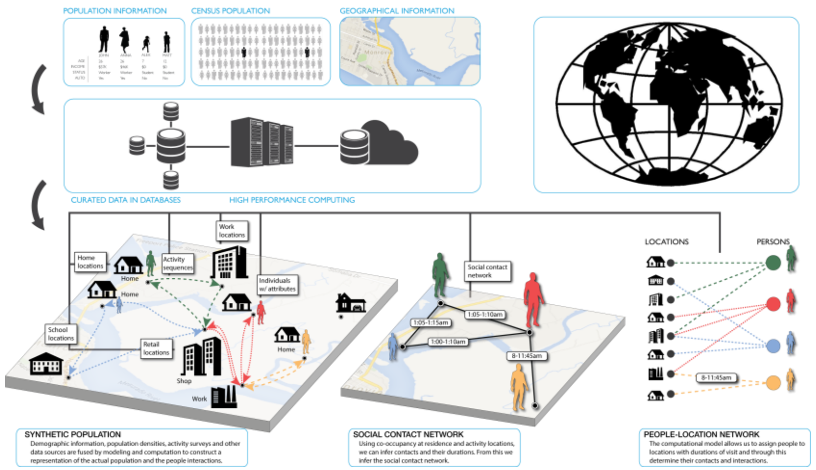




Agent-based Model (ABM)

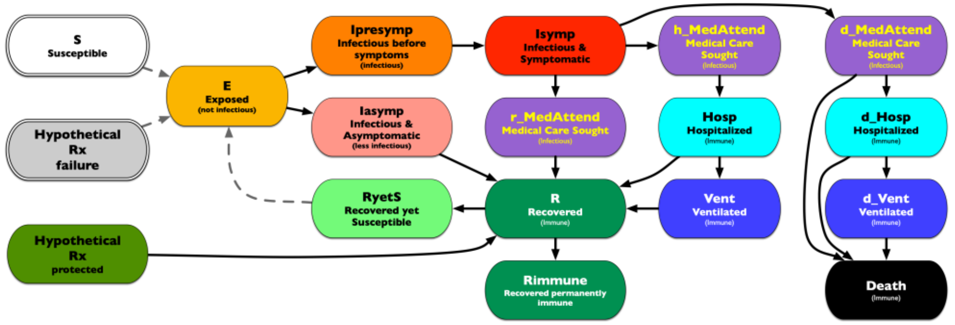
EpiHiper: Distributed network-based stochastic disease transmission simulations

- 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



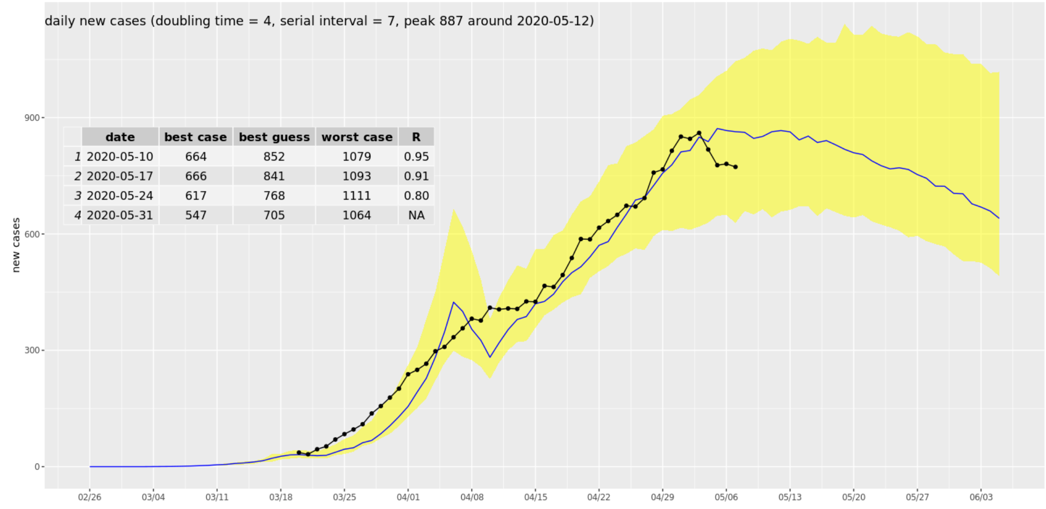
Detailed Disease Course of COVID-19

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

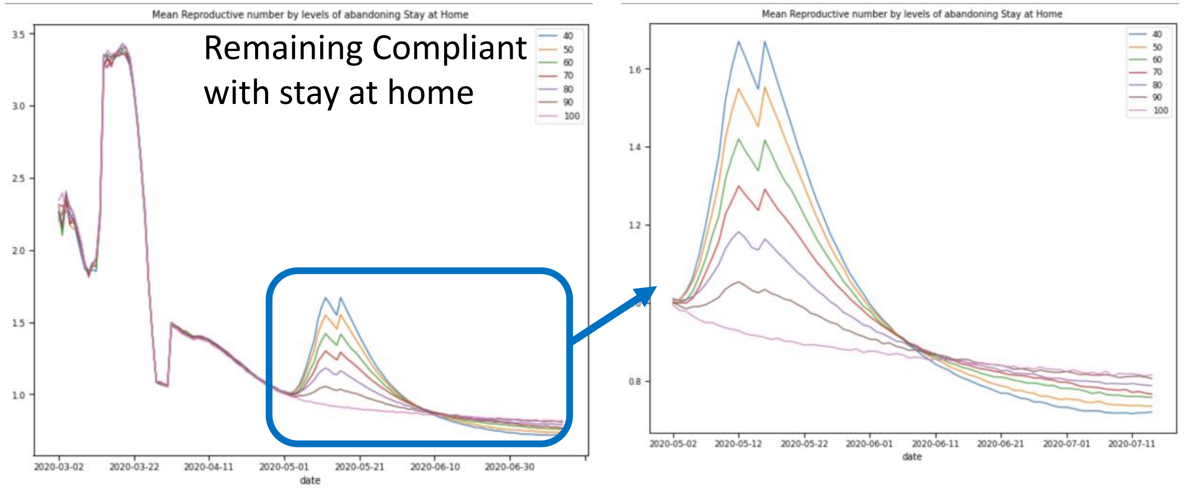
ABM Social Distancing Rebound Study Design

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