Network Systems Science & Advanced Computing

Biocomplexity Institute & Initiative

University of Virginia

Estimation of COVID-19 Impact in Virginia

July 22nd, 2020

(data current to July 21st)

Biocomplexity Institute Technical report: TR 2020-090

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biocomplexity.virginia.edu

Who We Are

- 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 the end of summer
  - 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

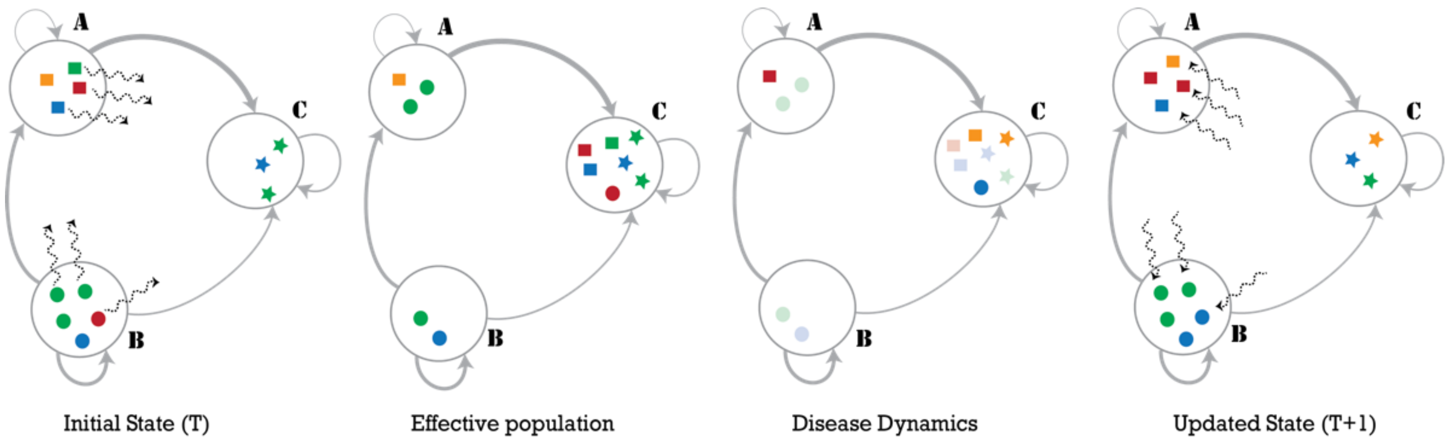
Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

- **More VDH health districts are experiencing surging activity, which continues to push VA upward. Considering the experience of other states in the nation, it is crucial to maintain control.**
- Recent model updates:
  - Method for identifying and adjusting Surge scenarios based on observed incidence, integrated with scenario selection for ”Best Fit” projection
  - Updated additional analyses to act as early indicators of surge and provide evidence for those surging
- Much of nation shows rapid rise following relaxation of social distancing with limited control measures.
- The situation is changing rapidly. Models will be updated regularly.

Model Configuration and Data Analysis

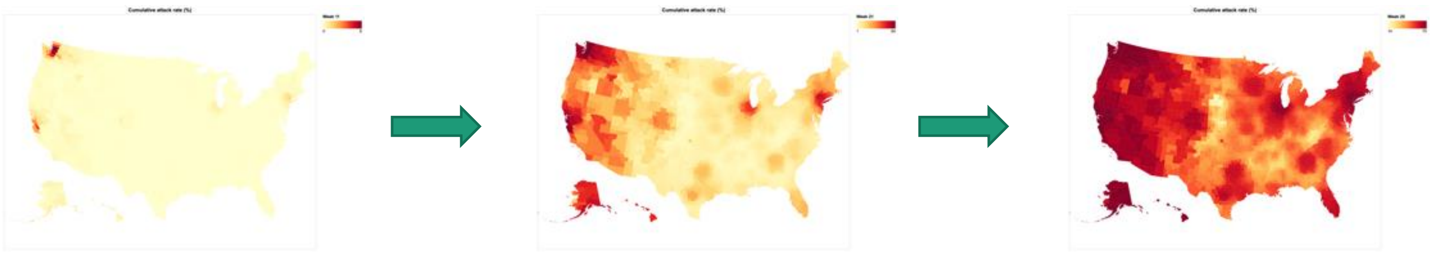
Simulation Engine – PatchSim

- Metapopulation model
  - Represents each population and its interactions as a single patch
  - 133 patches for Virginia counties and independent cities
- Extended SEIR disease representation
  - Includes asymptomatic infections and treatments
- Mitigations affect both disease dynamics and population interactions
- Runs fast on high-performance computers
  - Ideal for calibration and optimization



S → E → I → R

Susceptible → Exposed → Infectious → Removed



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

Model Configuration

- **Transmission:** Parameters are calibrated to the observed case counts
  - **Reproductive number:** 2.1 - 2.3
  - **Infectious period** (time of infectiousness before full isolation): 3.3 to 5 days
- **Initial infections:** Start infections from confirmed cases by county
  - Timing and location based on onset of illness from VDH data
  - Assume 15% detection rate, so one confirmed case becomes ~7 initial infections
- **Mitigations:** Intensity of social distancing rebound and control sustaining mitigations into the future are unknowable, thus explored through 5 scenarios

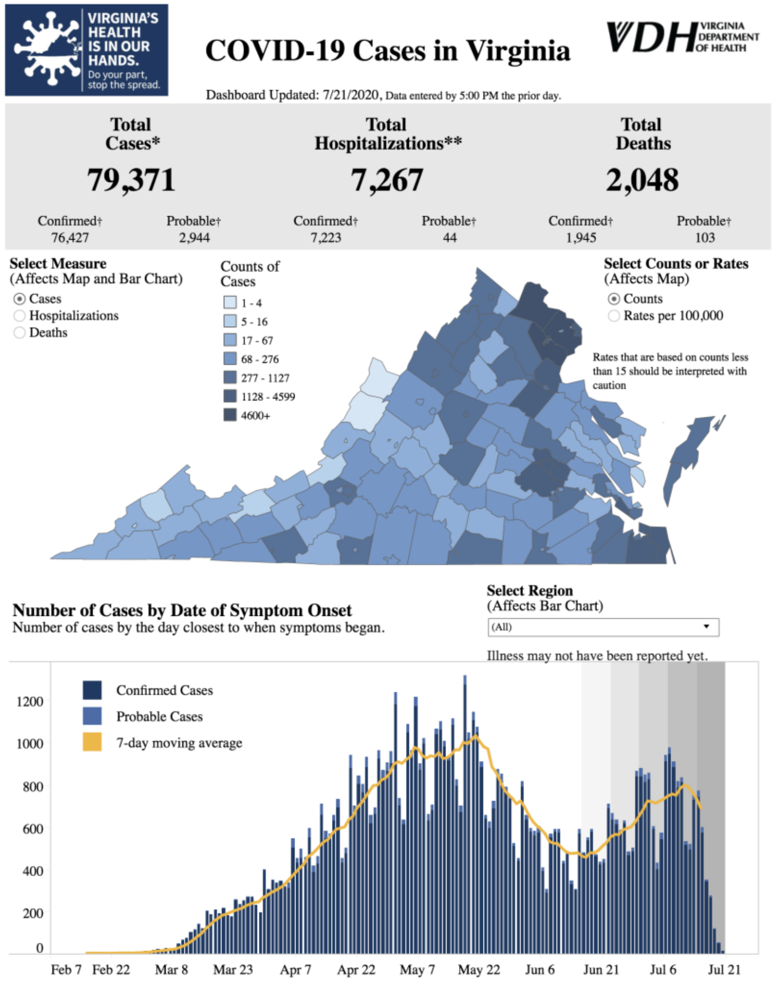
Full Model Parameters

	Parameter	Values	Description
Transmission	Transmissibility (R_0)[1]	2.2 [2.1 – 2.3]	Reproductive number
	Incubation period[1]	5 days	Time from infection to infectious
	Infectious period[1]	3.3 - 5 days	Duration of infectiousness
	Infection detection rate[3]	15%	1 confirmed case becomes ~7 initial infections
	Percent asymptomatic[1]	50%	Infected individuals that don't exhibit symptoms
Resources	Onset to hospitalization[1]	5 days	Time from symptoms to hospitalization
	Hospitalization to ventilation[1]	3 days	Time from hospitalization to ventilation
	Duration hospitalized	8 days	Time spent in the hospital [4]
	Duration ventilated[2]	14 days	Time spent on a ventilator
	Percent hospitalized[1]	5.5% (~20% of confirmed)	Symptomatic individuals becoming hospitalized
	Percent in ICU[1]	20%	Hospitalized patients that require ICU
	Percent ventilated[1]	70%	ICU patients requiring ventilation
	Percent Fatality	1.35%	Symptomatic individuals who die

1 CDC COVID-19 Modeling Team. "Best Guess" scenario. Planning Parameters for COVID-19 Outbreak Scenarios. Version: 2020-03-31.
2 Up-to-date. COVID-19 Critical Care Issues. https://www.uptodate.com/contents/coronavirus-disease-2019-covid-19-critical-care-issues?source=related_link (Accessed 13APRIL2020)
3 Li et al., *Science* 16 Mar 2020:eabb3221 https://science.sciencemag.org/content/early/2020/03/24/science.abb3221 (Accessed 13APRIL2020)
4 Personal communications, UVA Health and Sentara (~500 VA based COVID patients)

Calibration Approach

- **Data:**
  - County level case counts by date of onset (from VDH)
  - Confirmed cases for model fitting
- **Model:** PatchSim initialized with disease parameter ranges from literature
- **Calibration:** fit model to observed data
  - Search transmissibility and duration of infectiousness
  - Markov Chain Monte Carlo (MCMC) particle filtering finds best fits while capturing uncertainty in parameter estimates
- **Spatial Adjustments:** VDH districts grouped to 3 tiers of growth during the Pause, with similarly scaled reductions then applied to the groups of districts
- **Project:** future cases and outcomes using the trained particles



Accessed 8am July 22, 2020
https://www.vdh.virginia.gov/coronavirus/

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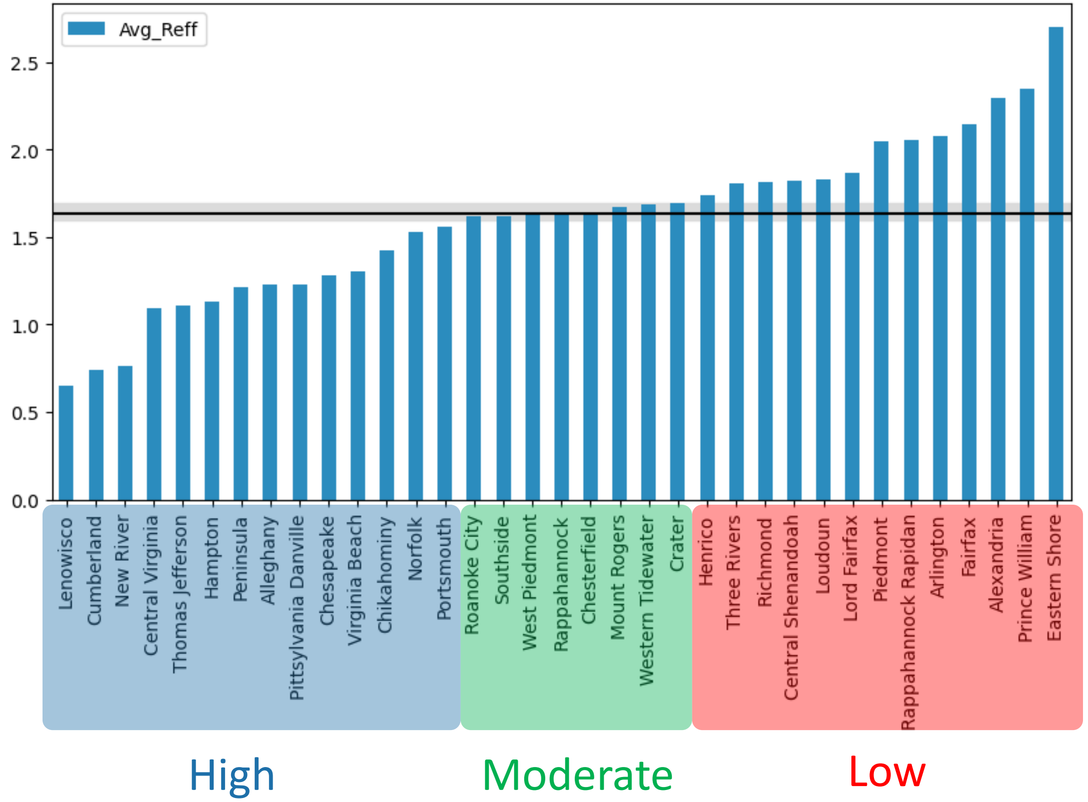
Spatial Adjustments at District Level

District Specific adjustments based on Growth during Pause

- Group districts by their mean growth from mid-April to mid-May (using model based R_{eff})
- Assign reductions during Pause, and beyond, to members of these groups
- Low reduction = 40%
- Moderate reduction = 45% (previous level)
- High reduction = 55%



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Scenarios: Past to Present

Pause from Social Distancing: Began on March 15th

- Lifted on May 15th (61 days), with two-week delay (75 days) for select counties*
- **Intensity**: Social distancing pauses and significantly reduces case growth, this level varies by VDH Health District and is fit through an analysis of growth rate during the Pause

Intensity of Rebound: Some districts rebounded following initial relaxation of Pause

- **Steady:** Intensity of effective mixing remains steady from Pause as infection control practices moderate increased interactions
- **Light:** Effective mixing returns to 1/6th of pre-pandemic levels
- **Full Rebound**: Interactions return completely (100%) to pre-pandemic levels, as a reference

Tracing and Isolation: Increased Testing Capacity coupled with infection control measures can limit the period of infectiousness without isolation

- **Better Detection**: Observed relative reductions in days from onset to diagnosis applied to infectious period from (30% → 45% → 30%) and remain stable into future for projections

* Select counties as mentioned by recent releases from Governor Northam's office
https://www.governor.virginia.gov/newsroom/all-releases/2020/may/headline-856741-en.html
https://www.governor.virginia.gov/newsroom/all-releases/2020/may/headline-856796-en.html

Mitigation Scenarios: Present to Future

Resurgence: Much of the nation experiencing a resurgence

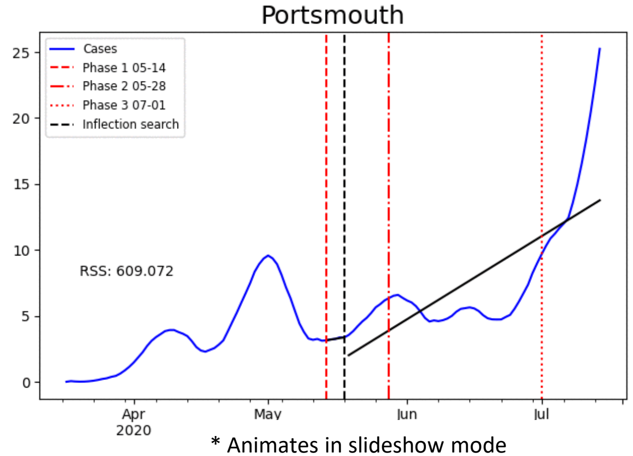
- Some districts in the Commonwealth also showing a resurgence
- 23 states surging: 28-day delay (avg) from relaxation to surge

Intensity of Surge: Difficult to predict with limited data

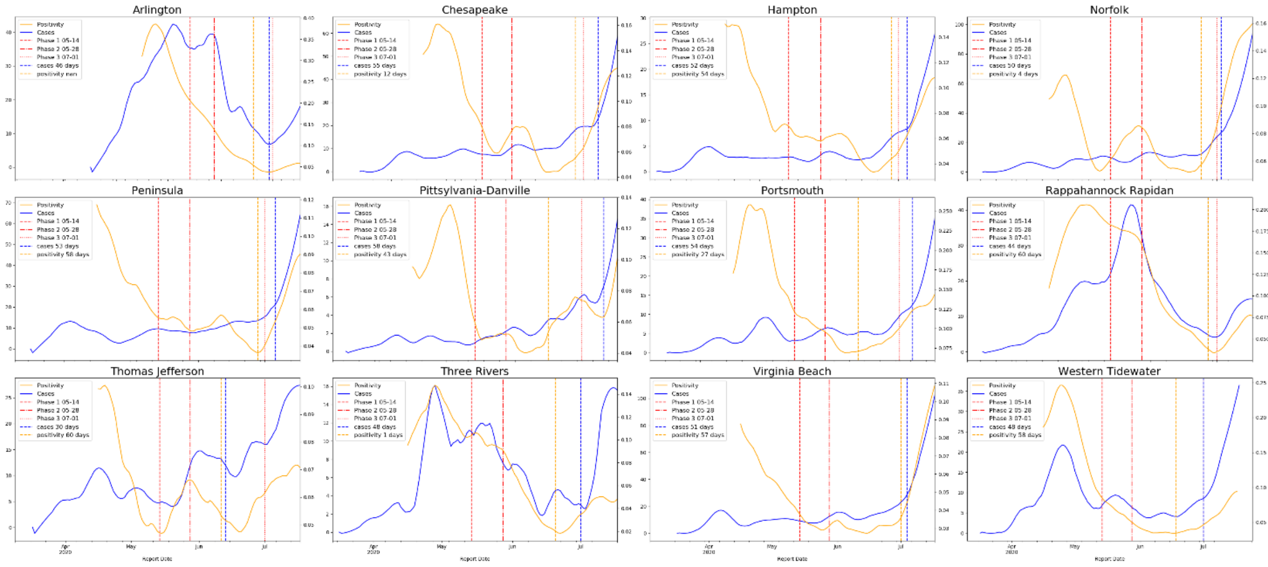
- **Strong Rebound:** Effective mixing returns 1/3 back to pre-pandemic levels

Timing of Surge: Present and Future

- Determine surging districts and timing through "hockey stick" fit
- Allow "Best Fit" method to select from "Surge" scenarios
- Default to 28 days from July 1st for districts without present surge



* Animates in slideshow mode



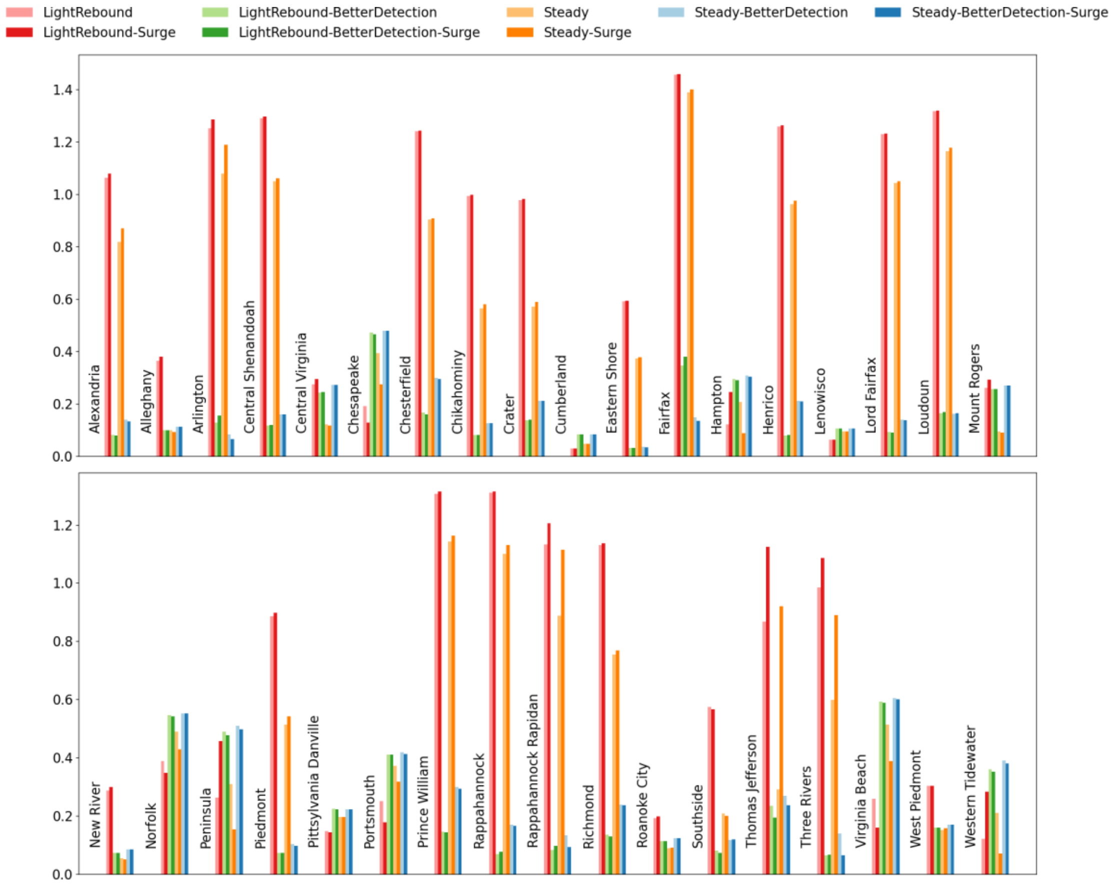
Twelve districts: Eastern region joined by others (mid-June to early July)

Eight Scenarios for Projection

Abbr	Rebound Intensity	Better Detection	Surge	Name
LR	Light	No	No	LightRebound
LR-S	Light	No	Yes	LightRebound-Surge
LR-BD	Light	Yes	No	LightRebound-BetterDetection
LR-BD-S	Light	Yes	Yes	LightRebound-BetterDetection-Surge
S	Steady	No	No	Steady
S-S	Steady	No	Yes	Steady-Surge
S-BD	Steady	Yes	No	Steady-BetterDetection
S-BD-S	Steady	Yes	Yes	Steady-BetterDetection-Surge

Selection of Best Fitting Projection

Recent incidence by district (last week) is measured against all eight projections, one with least error is selected as the “Best Fit” projection



Abbr	Name	# of Districts (last wk)
LR	LightRebound	3 (2)
LR-S	LightRebound-Surge	4 (3)
LR-BD	LightRebound-BetterDetection	10 (12)
LR-BD-S	LightRebound-BetterDetection-Surge	6 (4)
S	Steady	2 (6)
S-S	Steady-Surge	7 (3)
S-BD	Steady-BetterDetection	1 (5)
S-BD-S	Steady-BetterDetection-Surge	2 (0)

- 19 districts have Surge projections as BestFit compared to 10 last week
- Continued movement towards “higher incidence” projections

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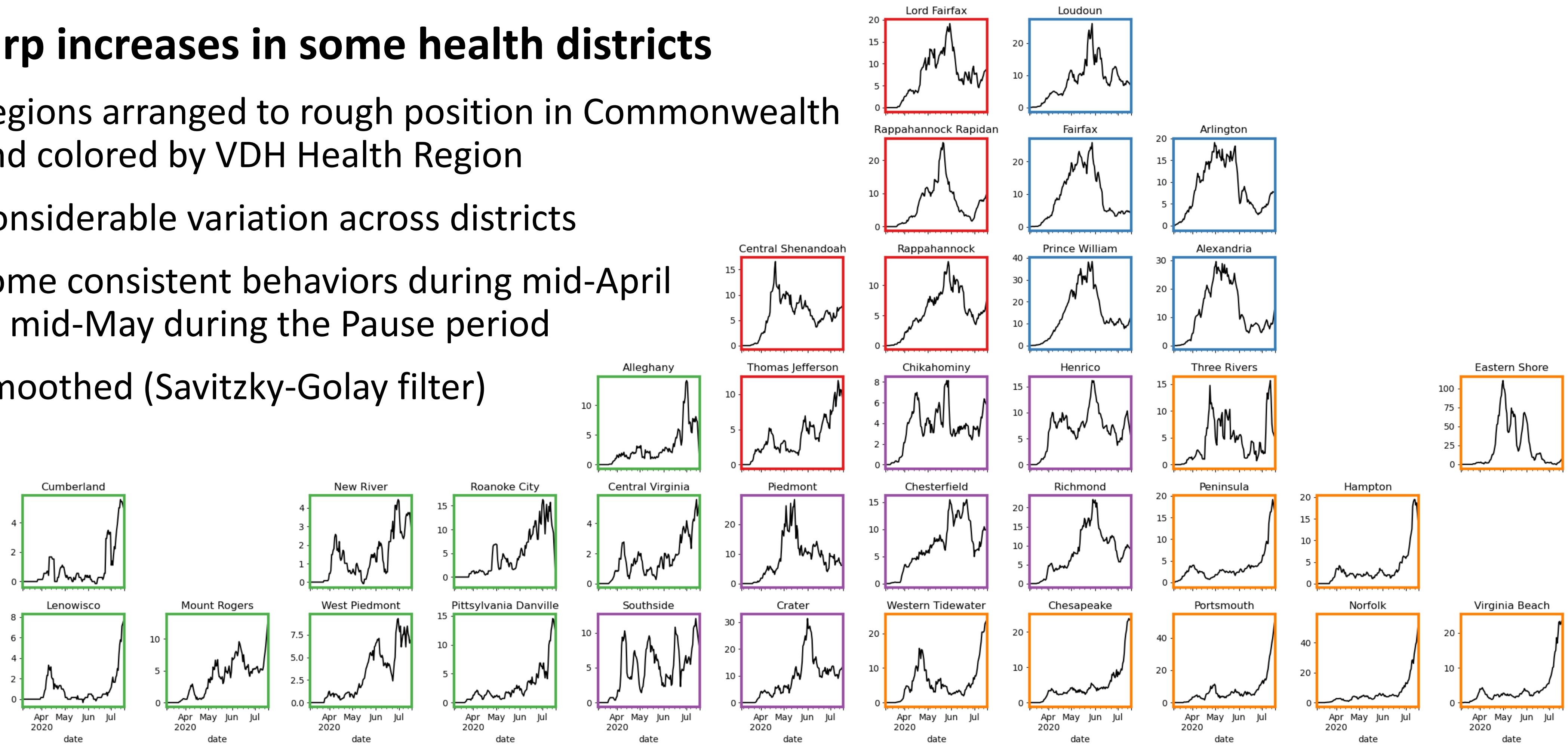
Data Analysis Supporting Model

Case Rate (per 100k) by VDH District

Sharp increases in some health districts

- Regions arranged to rough position in Commonwealth and colored by VDH Health Region
- Considerable variation across districts
- Some consistent behaviors during mid-April to mid-May during the Pause period
- Smoothed (Savitzky-Golay filter)



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Estimating Effects of Social Distancing

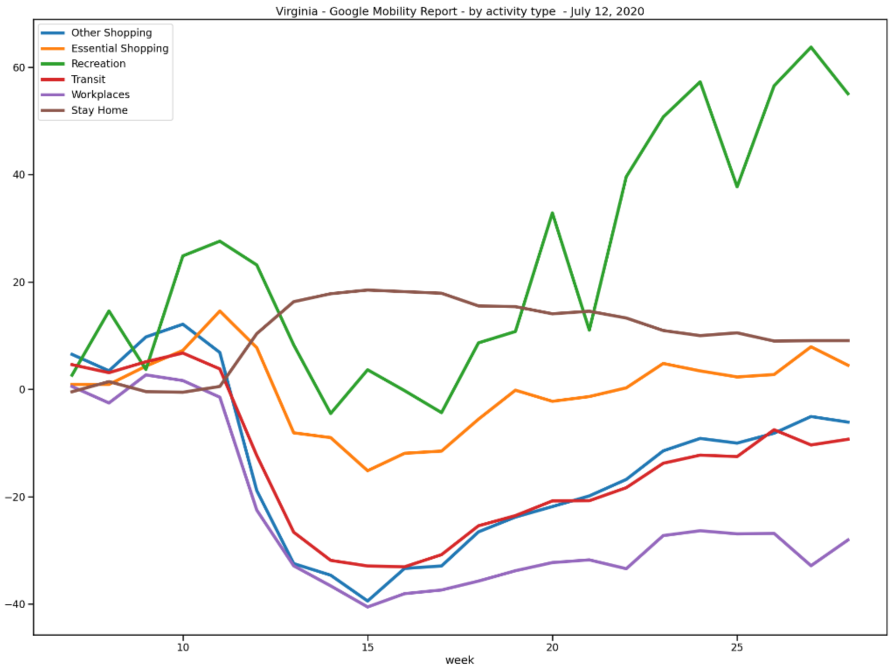
Mobility data shows pause mid-March, slow rebound starting in May

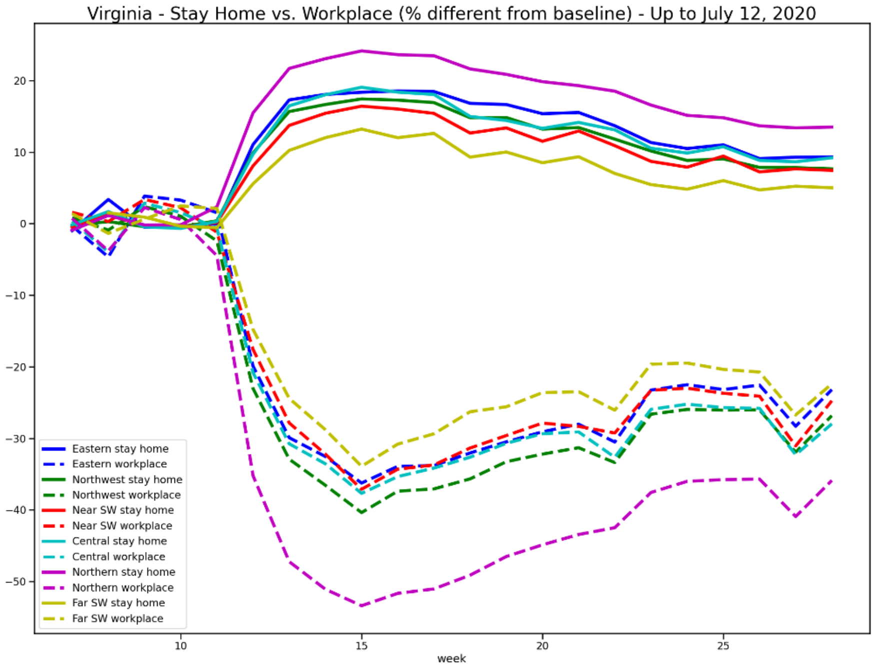
Google Mobility data shows continued slow rebound

(as of July 12th)

https://www.google.com/covid19/mobility/

- Continued reduction of those staying at home, very slow and stable reductions
- Other activities show vaster increases with grocery / retail nearly back to baseline
- Parks and recreation show significant increase





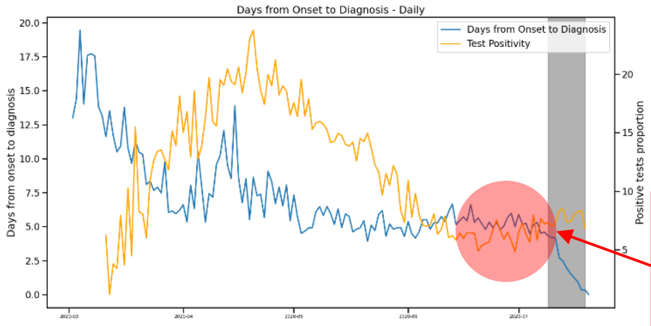
Changes in Case Detection

VDH data show changes in time from Symptom Onset to Diagnosis

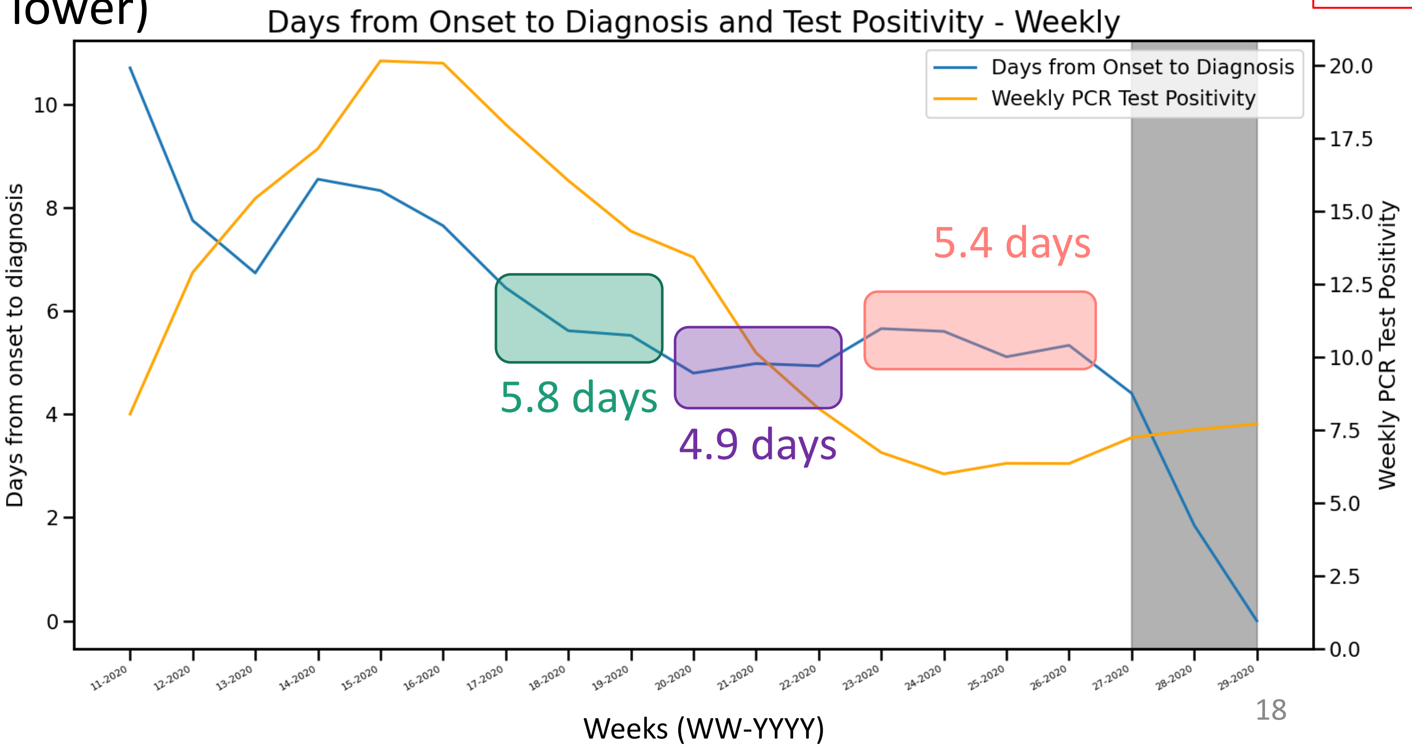
Days to Diagnosis dropped but rebounding

- Mid March to Late April = 7.8 days
- Late April to Mid May = 5.8 days (25% lower)
- Mid May to early June = 4.9 days (37% lower)
- Early June to early July = 5.4 days (31% lower)

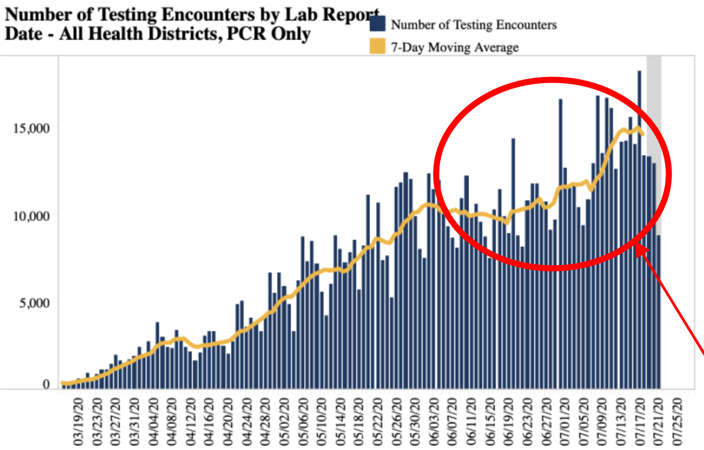
Test positivity vs. Onset to Diagnosis



Recent flattening / slight rise in test positivity



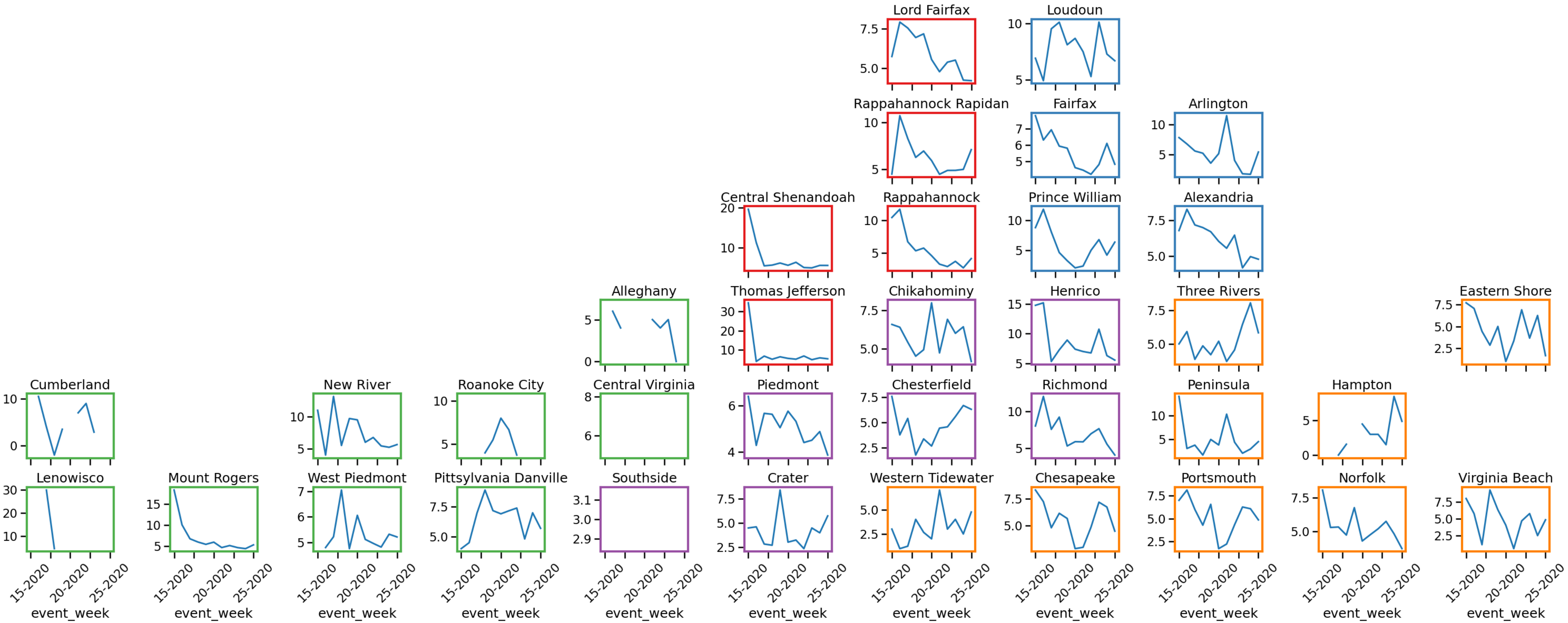
Testing Encounters and test positivity have steadied and increased



Recent flattening then slight rise in total tests

Accessed 8am July 22nd, 2020
https://www.vdh.virginia.gov/coronavirus/

Changes in Case Detection* – by district



*up to the early July when data is stable

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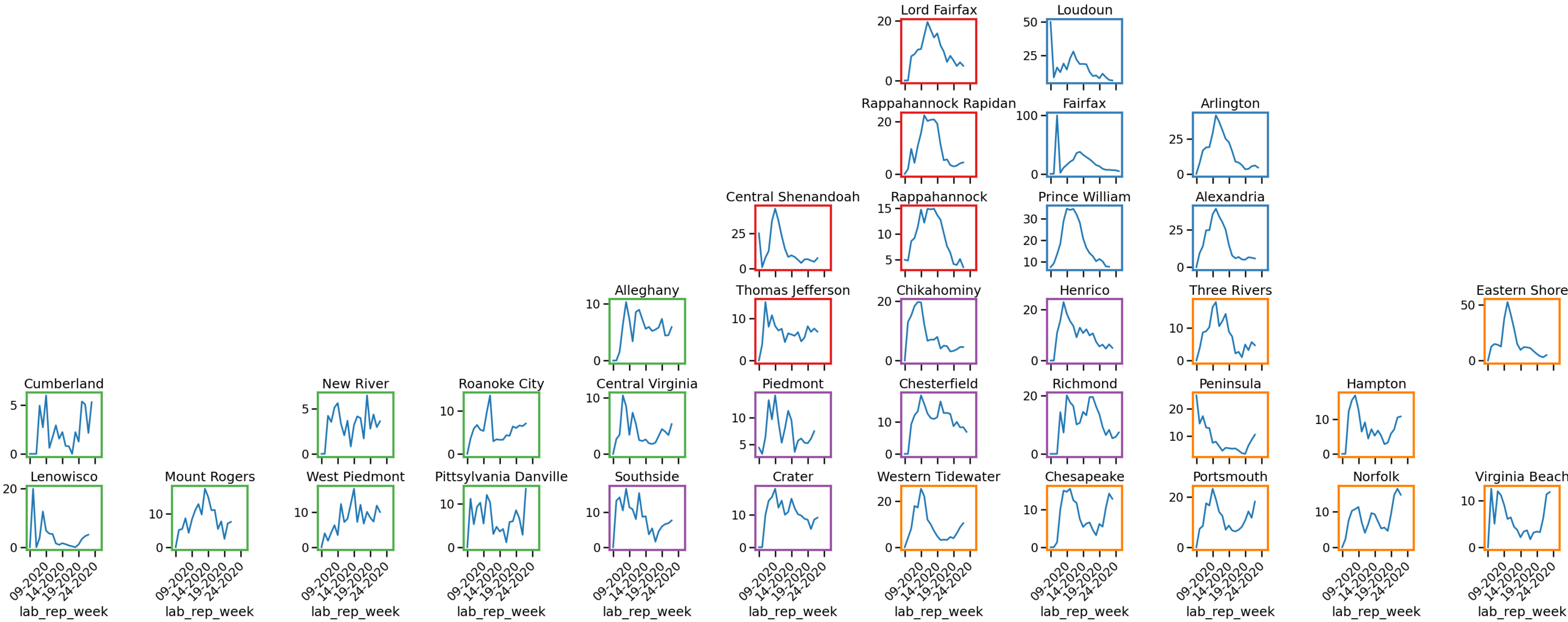
Changes in Test Positivity – by district



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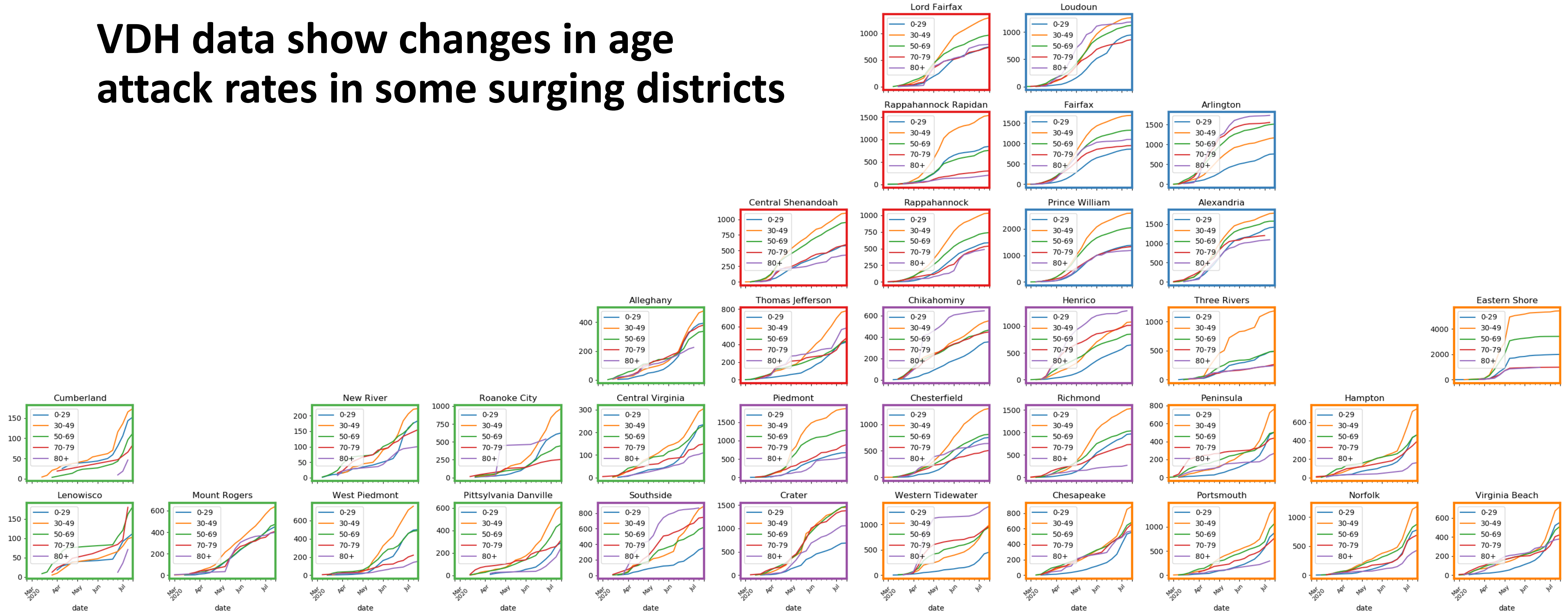
Case Attack rate (per 100k) by Age-group and District

VDH data show changes in age attack rates in some surging districts



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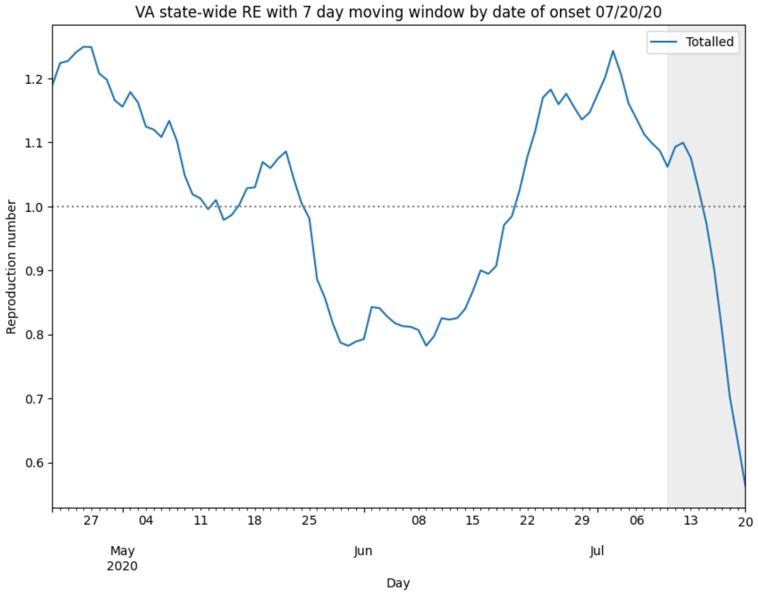
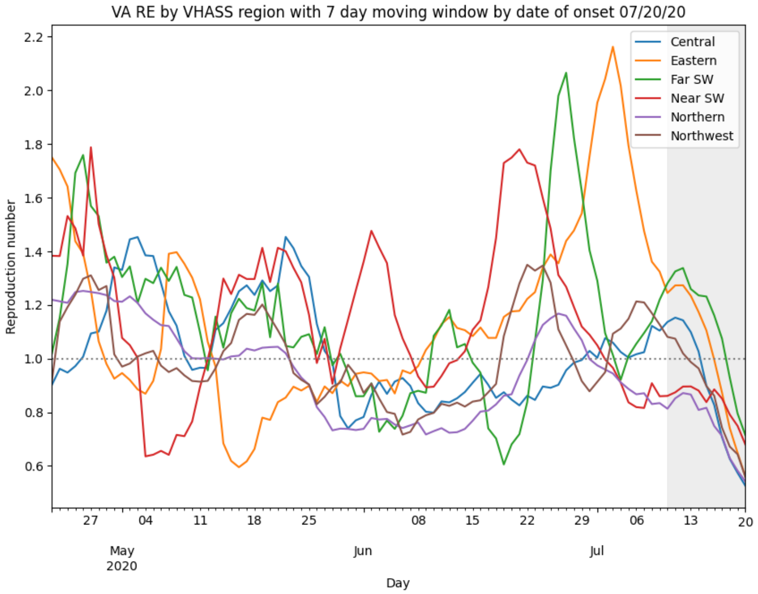
Estimating Daily Reproductive Number

July 11th Estimates

Region	Current R_e	Diff Last Week
State-wide	1.093	-0.044
Central	1.152	0.169
Eastern	1.273	-0.667
Far SW	1.325	0.376
Near SW	0.874	-0.050
Northern	0.852	0.000
Northwest	1.074	0.024





Methodology

- Wallinga-Teunis method as implemented in EpiEstim[1] R package
- Based on Date of Onset of Symptoms
- Uses serial interval to estimate R_e over time: 6 days (2 day std dev)

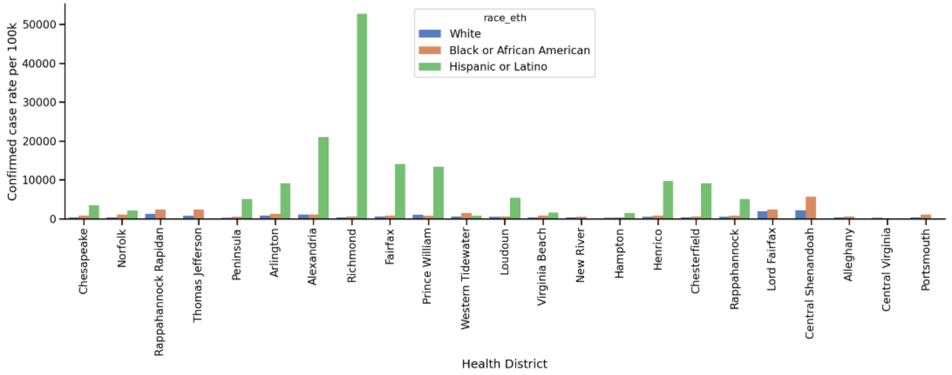
Recent Estimates subject to revision as more data comes in

- Date of onset unstable in last 7-14 days

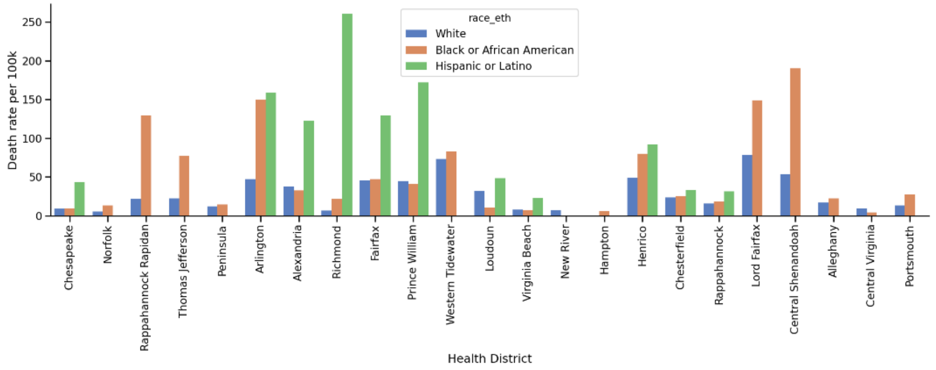
1. Anne Cori, Neil M. Ferguson, Christophe Fraser, Simon Cauchemez. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. American Journal of Epidemiology, Volume 178, Issue 9, 1 November 2013, Pages 1505–1512, https://doi.org/10.1093/aje/kwt133

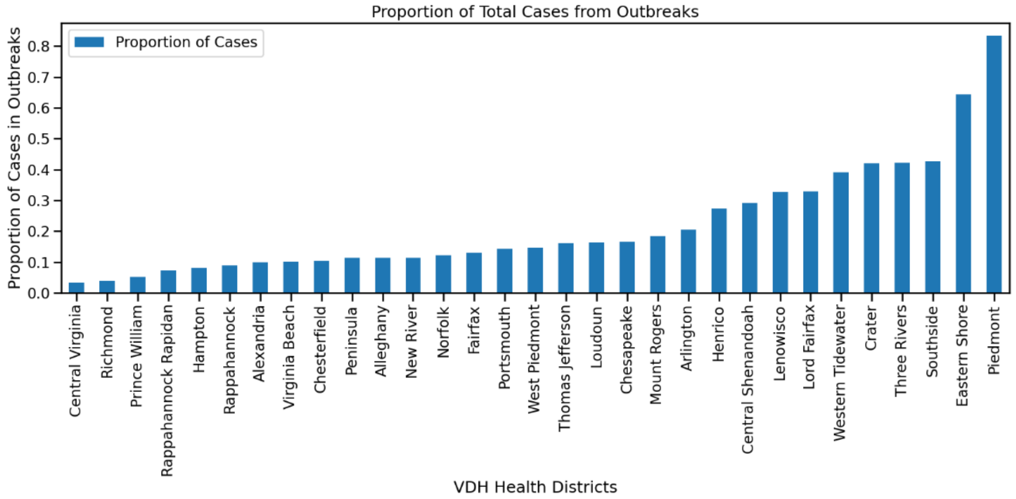
Impact of Race / Ethnicity & Outbreaks

Confirmed Case Rate



Death Rate





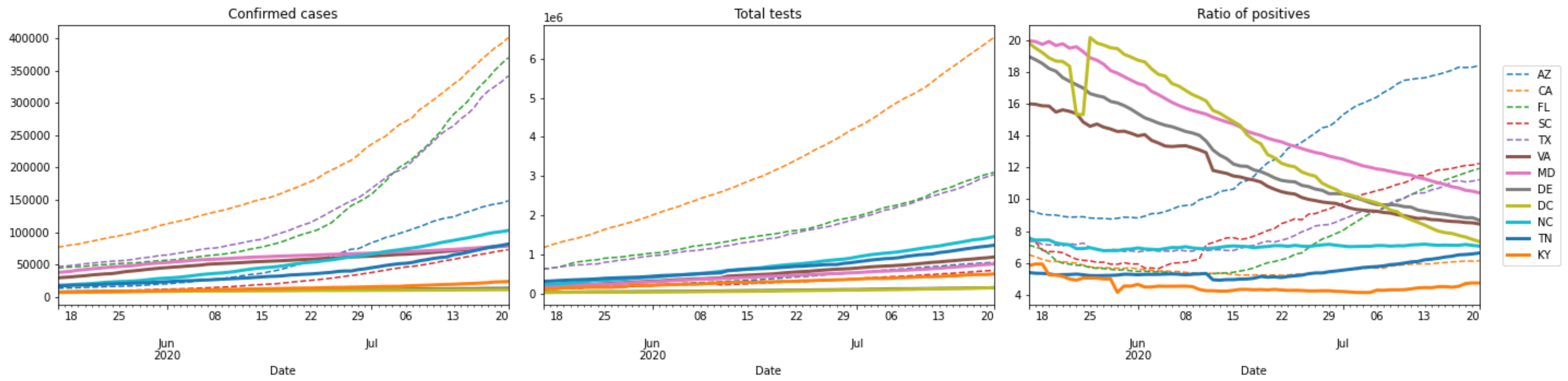
Different Races and Ethnicities disproportionally affected

- Hispanic population bears large burden of disease compared to population size

Outbreak Events are hard to predict and affect model fits

- Eastern Shore has 60% of cases from 10 outbreaks
- Fairfax most outbreaks but relatively low proportion

Other State Comparisons



Several States continue to experience large surges in cases

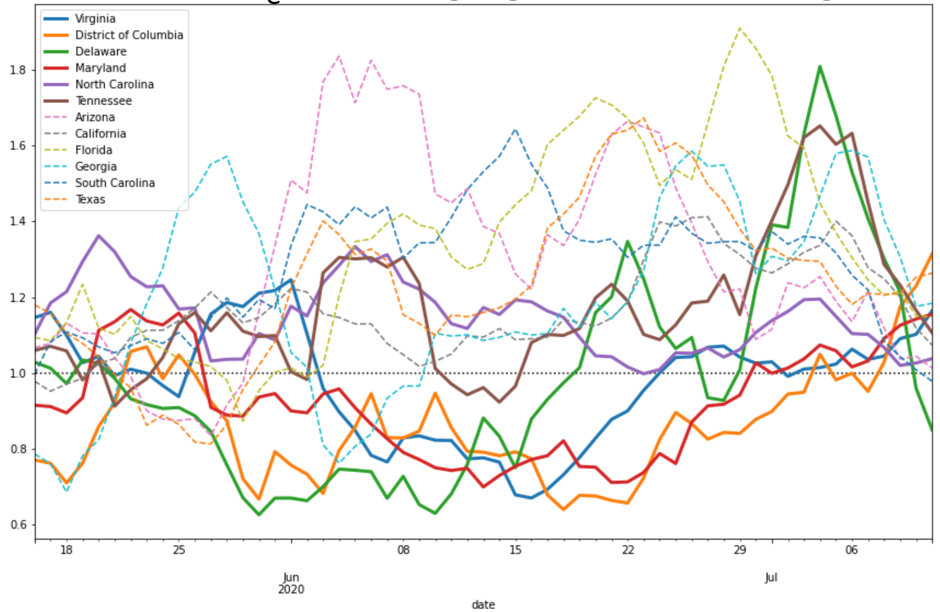
- Some of these surging states show no signs of abating, others, mainly in the west continue to slow down

R_e Estimates for VA and neighbors show upward trend

- Virginia and others above 1, and have been for several weeks
- Sharp rise in R for TN and DE has retreated a bit

Signs of resurgence: Plateauing or increase in test positivity and R above 1 for several weeks

Estimated R_e* for surging States and Neighbors



* Based on confirmed cases per day

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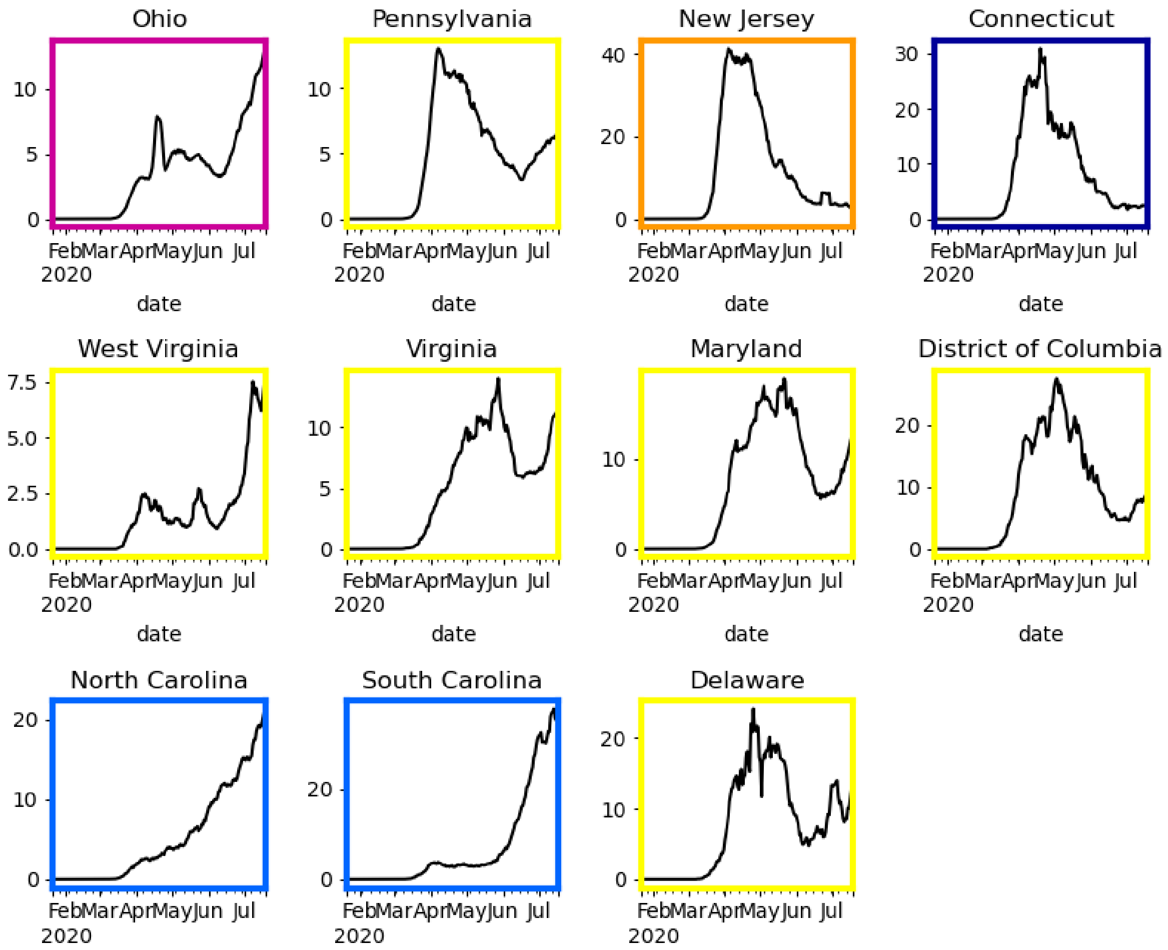
Other State Comparisons



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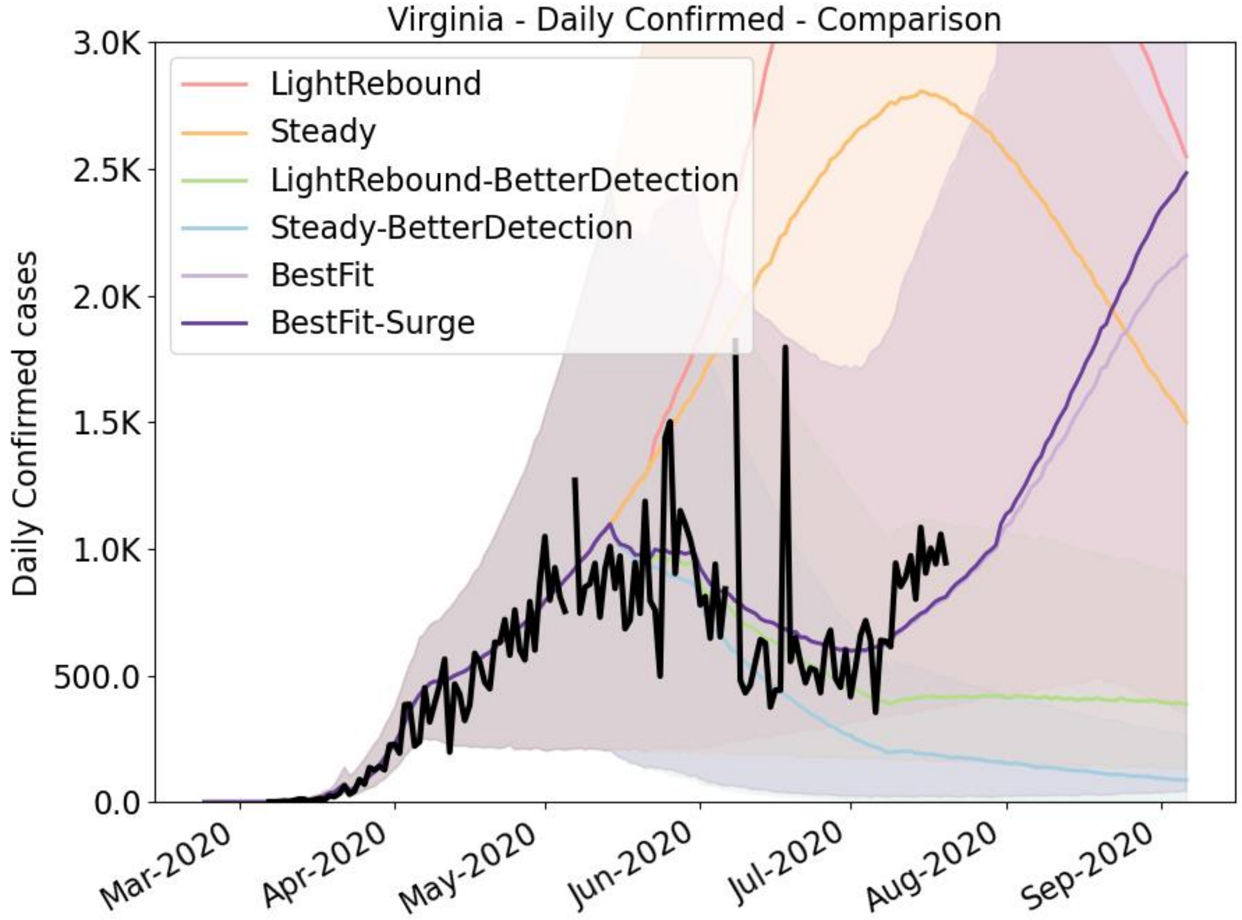
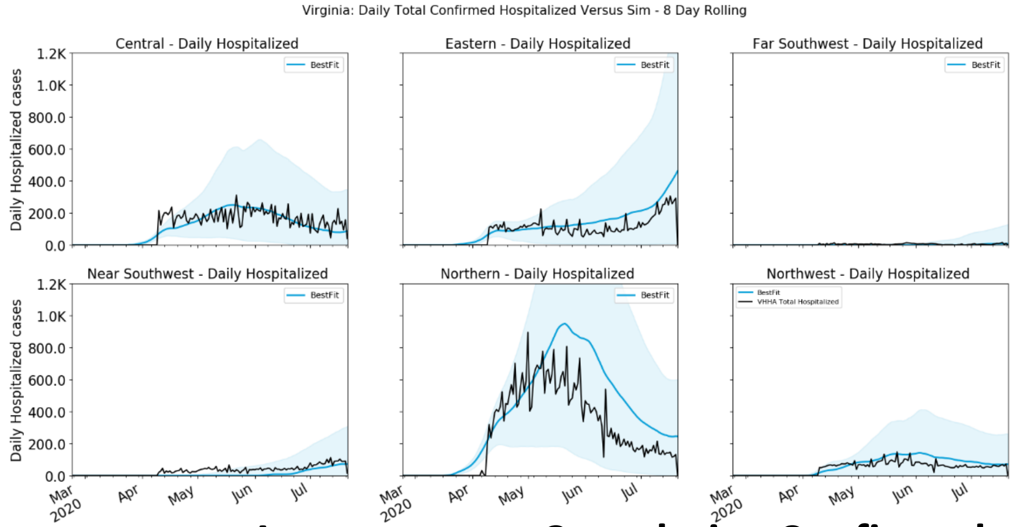
Model Results

Outcome Projections

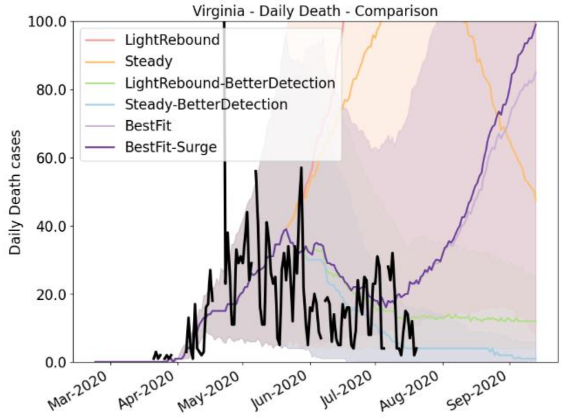
Confirmed cases



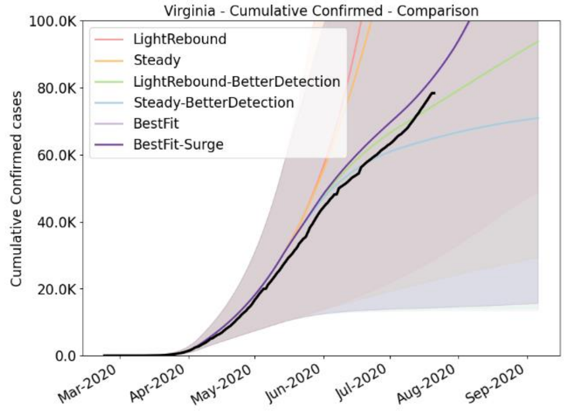
Hospital occupancy



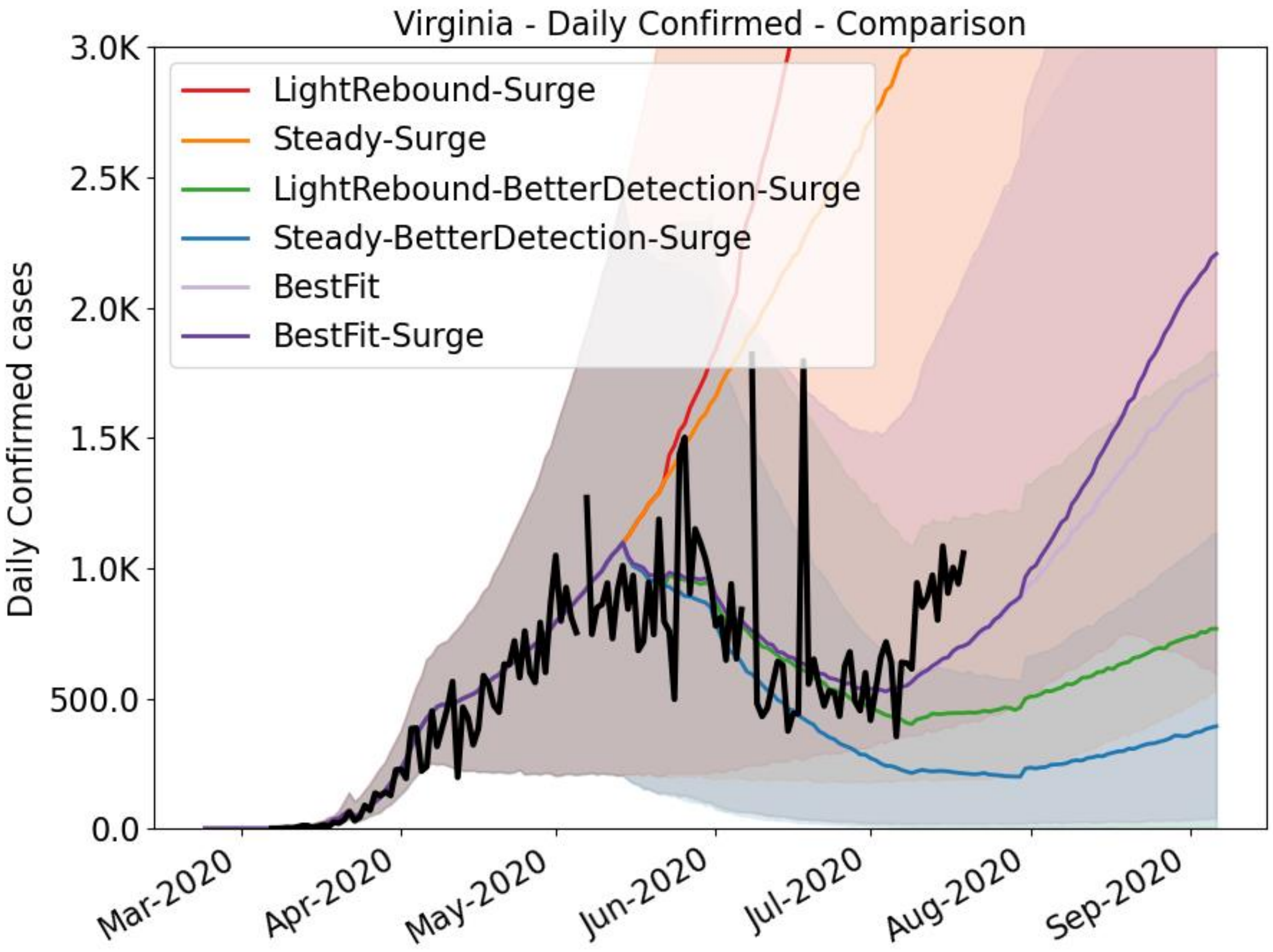
Deaths



Cumulative Confirmed cases



Outcome Projections – with Surge



Weekly New Confirmed Cases*

Week Ending	Best Fit	Best Fit w/ Surge
7/12/20	4,333	4,374
7/19/20	5,033	5,084
7/26/20	5,799	5,868
8/2/20	6,771	6,889
8/9/20	8,200	8,597
8/16/20	9,726	10,416
8/23/20	11,386	12,420
8/30/20	13,033	14,447
9/6/20	14,404	16,322

*Numbers are medians of projections

District Level Projections - Daily

Best fitting projections by District

- Projections that best fit recent trends
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

Abbr	Name	# of Districts (last wk)
LR	LightRebound	3 (2)
LR-S	LightRebound-Surge	4 (3)
LR-BD	LightRebound-BetterDetection	10 (12)
LR-BD-S	LightRebound-BetterDetection-Surge	6 (4)
S	Steady	2 (6)
S-S	Steady-Surge	7 (3)
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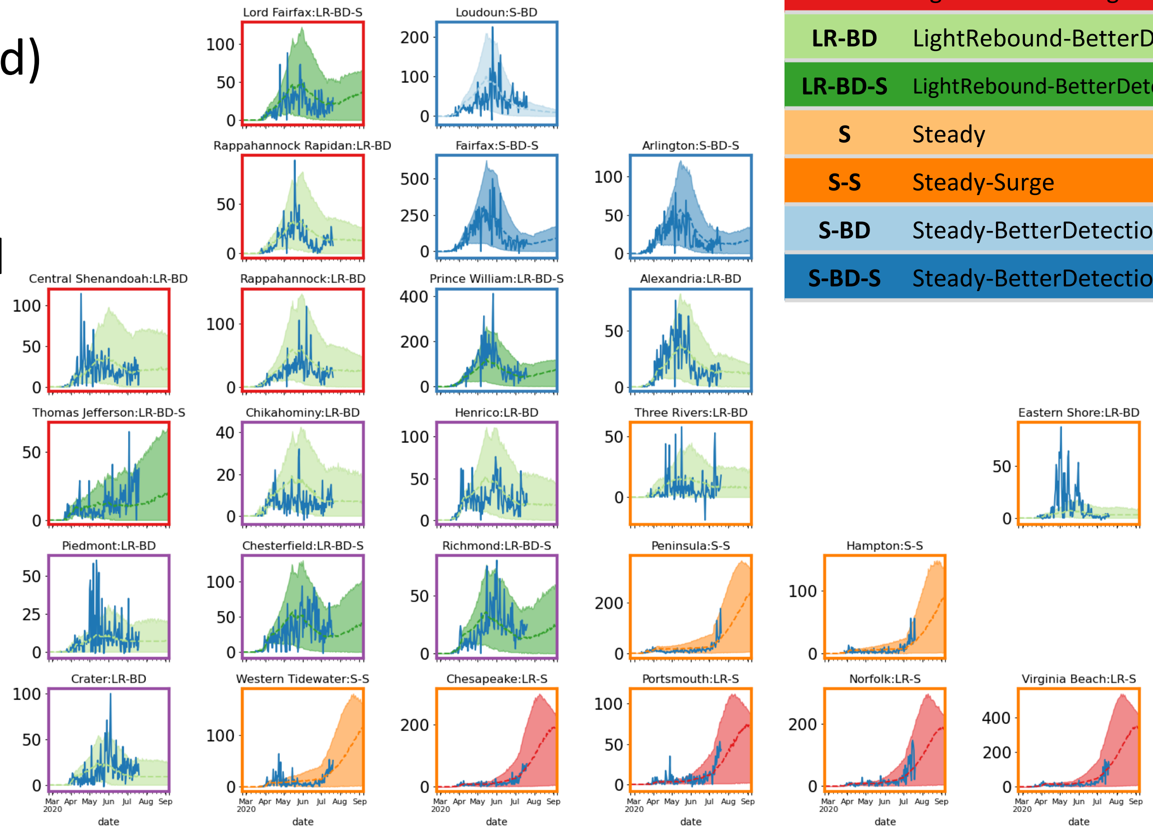
S-BD-S	Steady-BetterDetection-Surge	2 (0)



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District Level Projections – Daily with Surge

Best fitting projections by District

- Projections that best fit recent trends with Surge assumed for all districts
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

Abbr	Name	# of Districts (last wk)
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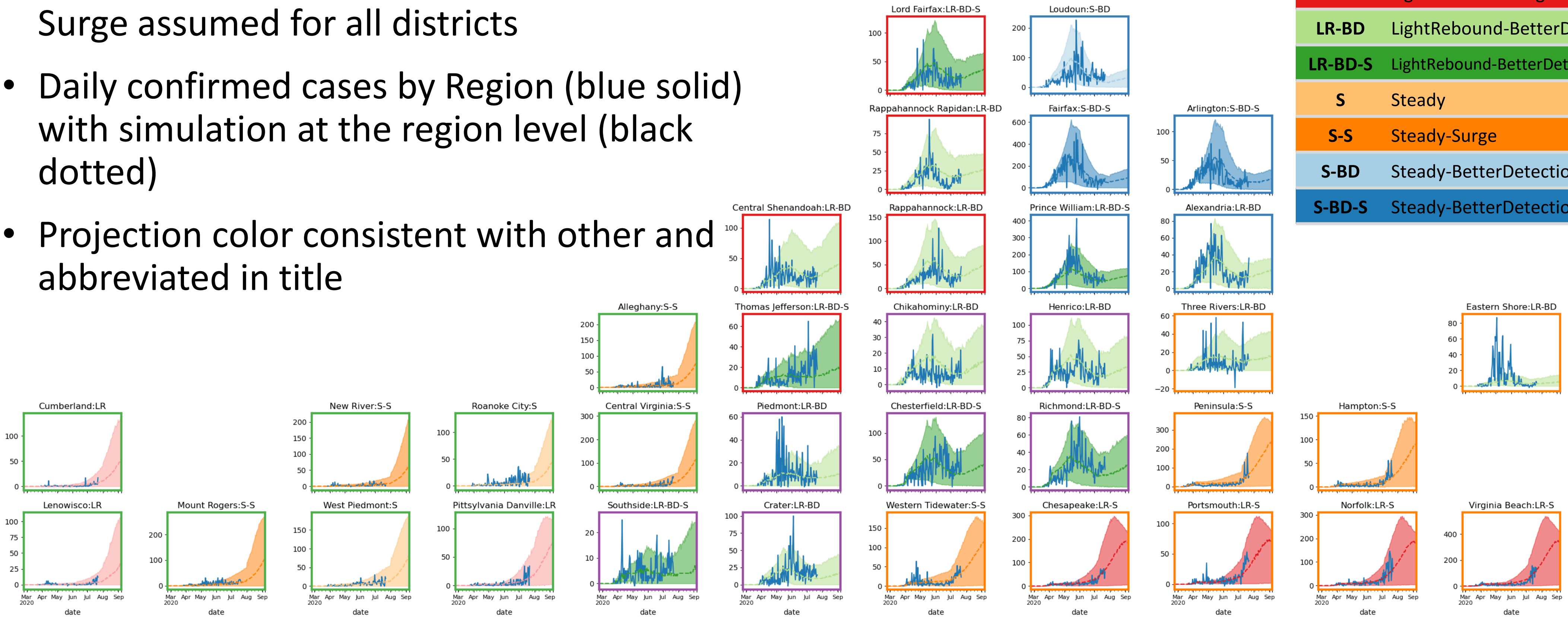

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District Level Projections - Cumulative

Best fitting projections by District

- Projections that best fit recent trends
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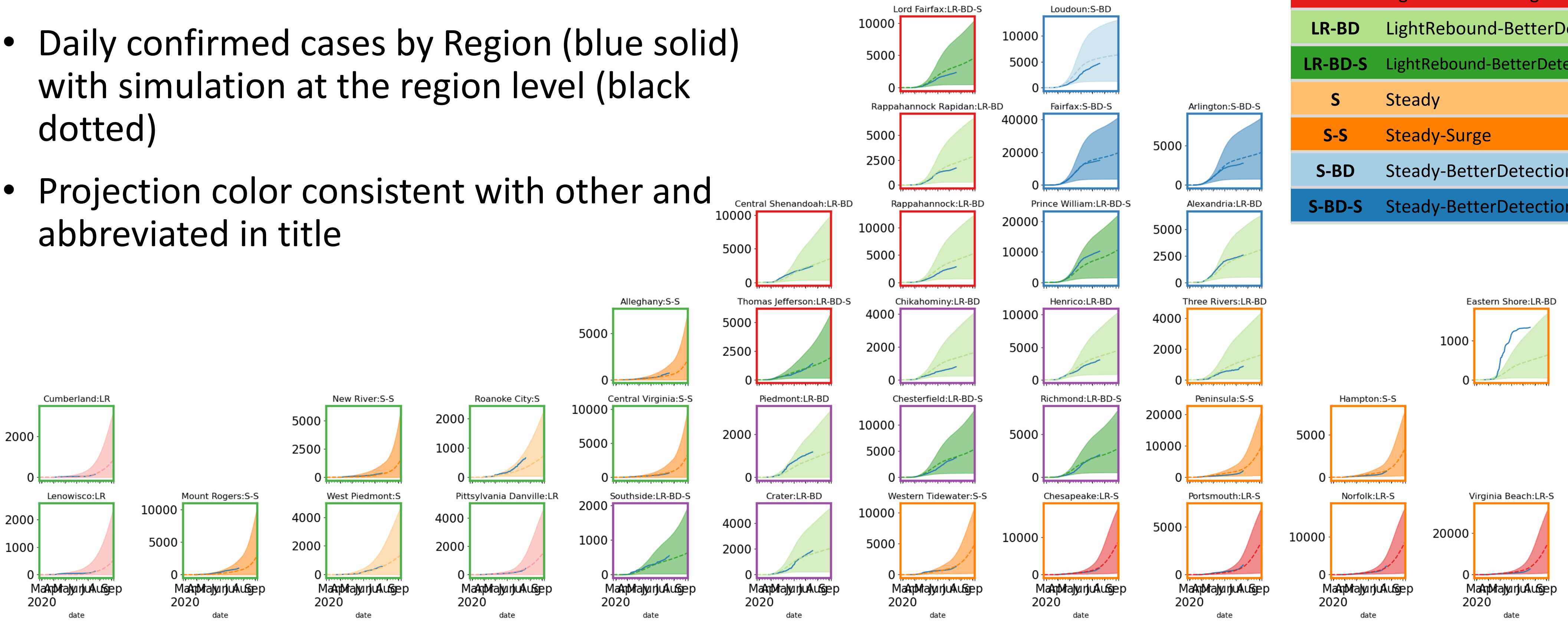

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District Level Projections – Cumulative with Surge

Best fitting projections by District

- Projections that best fit recent trends with Surge assumed for all districts
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

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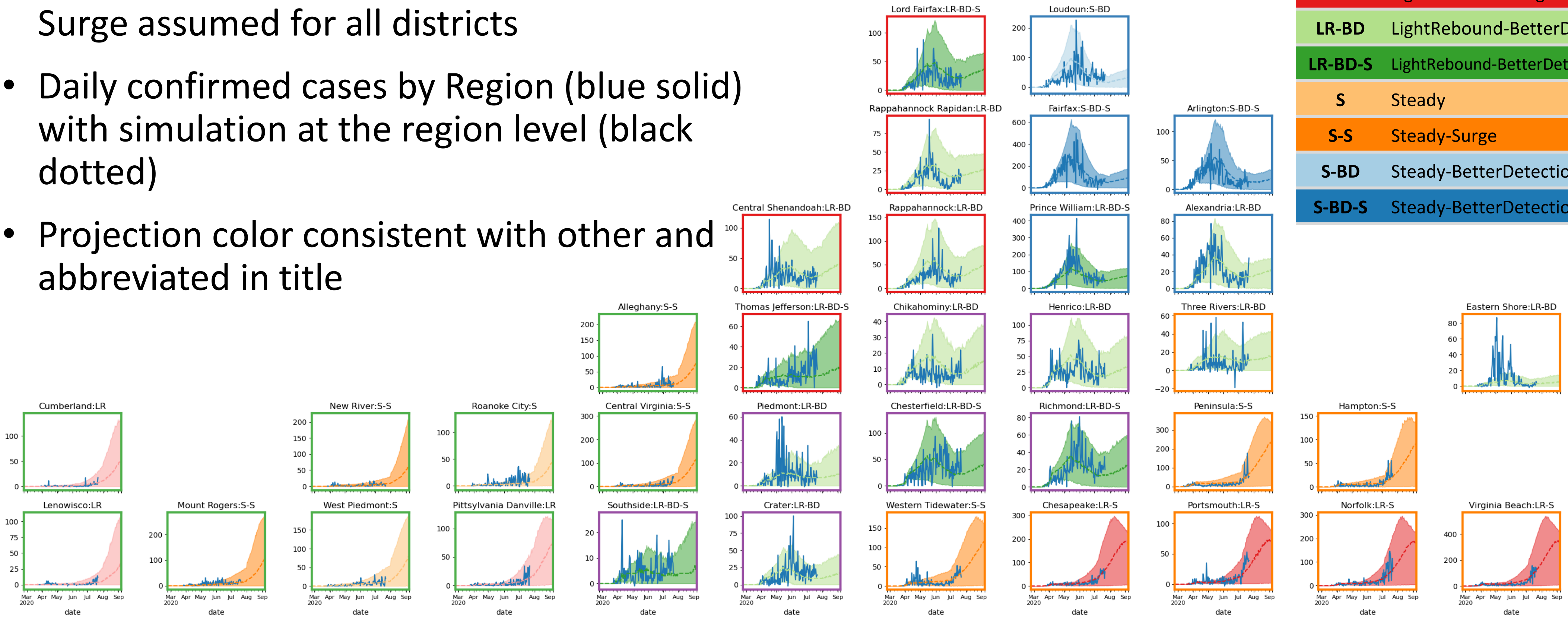
LR	LightRebound	3 (2)
LR-S	LightRebound-Surge	4 (3)
LR-BD	LightRebound-BetterDetection	10 (12)
LR-BD-S	LightRebound-BetterDetection-Surge	6 (4)
S	Steady	2 (6)
S-S	Steady-Surge	7 (3)
S-BD	Steady-BetterDetection	1 (5)
S-BD-S	Steady-BetterDetection-Surge	2 (0)



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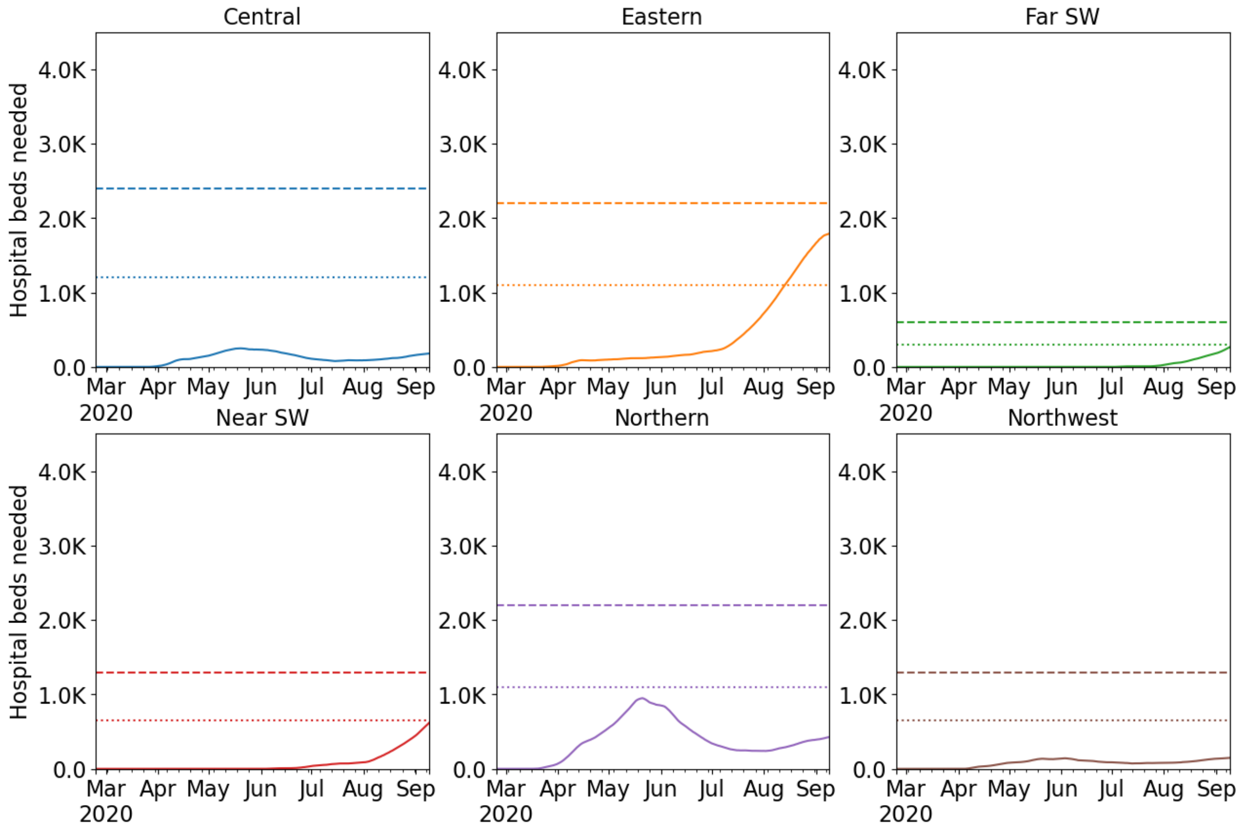
Hospital Demand and Capacity by Region

Capacities by Region – BestFit- Surge

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



- Based on current best fits with potential surge
    - Eastern region exceeds 80% capacity in mid-August, current model keeping pace with observed increases in Eastern region
    - Multiple regions (Near SW, Far SW, Eastern and Northern) may near their capacity in September
    - Northern may begin to rise again here at the end of July
- Activity in neighboring states and reopening of schools/universities may make this more likely

* Assumes average length of stay of 8 days

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A new forecasting framework nearing completion

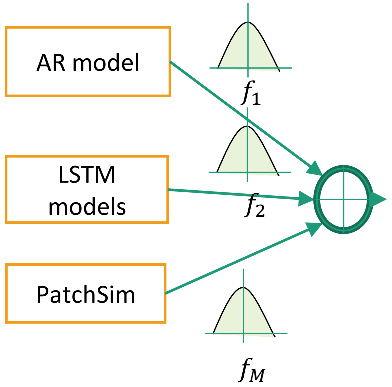
- Augmenting “forecast through projection selection” with ensemble of statistical and mechanistic models
- Methods included:
  - Autoregressive methods with mobility data, google trends, other county case counts, and weather data as exogenous regressors.
  - Long short-term memory deep learning models with additional mobility data, Google search trends, weather data for training.
  - Mechanistic models for relative ease of incorporation of intervention scenarios.
- Forecasts from multiple models (methods) combined to yield probabilistic forecasts: Bayesian Model Averaging

$$P(y|f_1, f_2, \dots, f_M) = \sum_{m=1}^{M} w_m g_m(y|f_m)$$

y = true value, f_m =forecast from m^{th} model

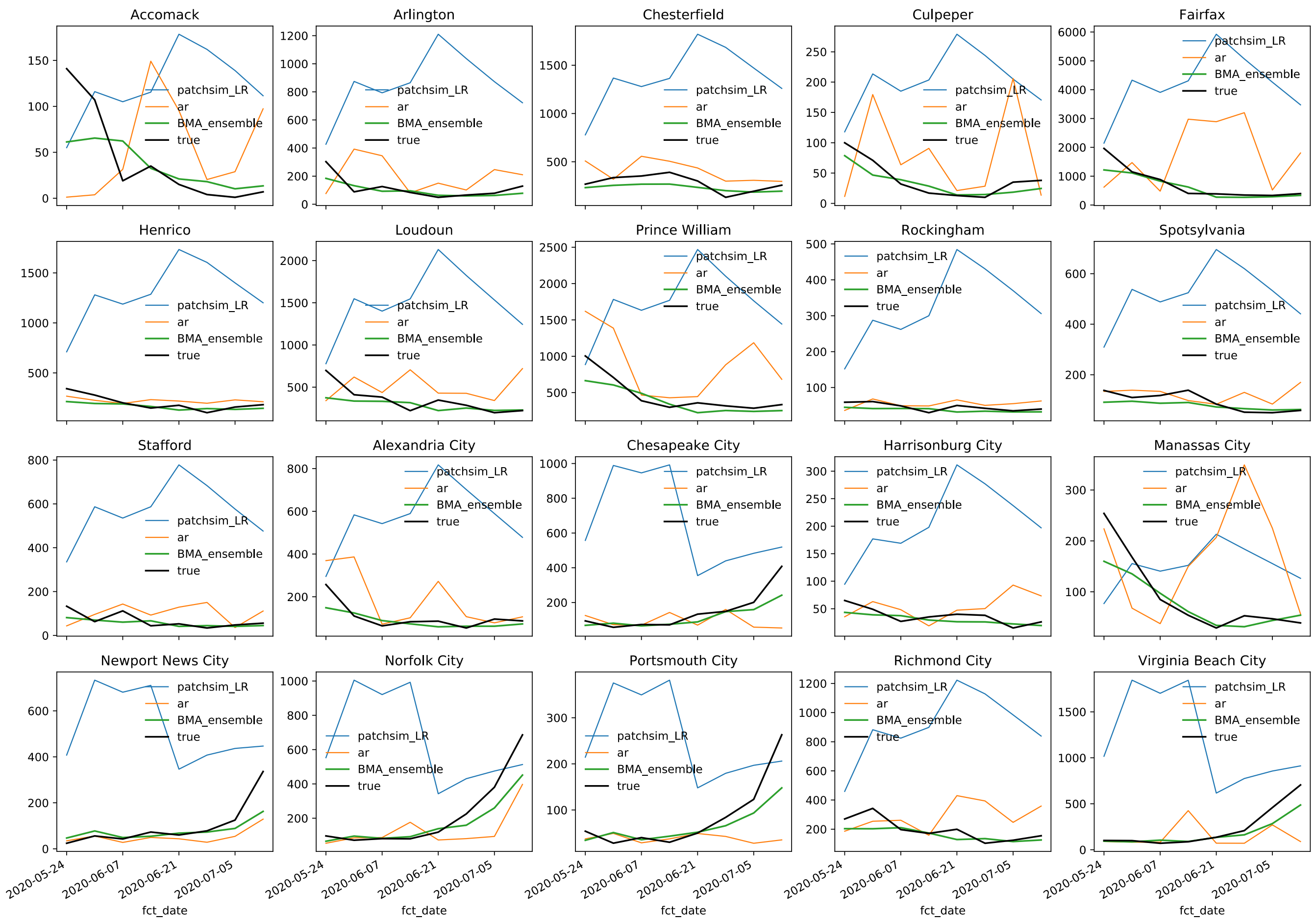
$g_m(y|f_m)$ = m^{th} model probabilistic forecast

w_m = weights assigned to m^{th} model forecast



A new forecasting framework performance

- Ensemble (green) captures both PatchSim scenarios (light rebound, blue) and other statistical (orange) and deep learning models (not plotted)
- Performance of the ensemble is better than any individual model alone
- Future scenarios can be baked into mechanistic models



Key Takeaways

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

- **More VDH health districts are experiencing surging activity, which continues to push VA upward. Considering the experience of other states in the nation, it is crucial to maintain control.**
- Recent model updates:
  - Method for identifying and adjusting Surge scenarios based on observed incidence, integrated with scenario selection for ”Best Fit” projection
  - Updated additional analyses to act as early indicators of surge and provide evidence for those surging
- Much of nation shows rapid rise following relaxation of social distancing with limited control measures.
- The situation is changing rapidly. Models will be updated regularly.

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

Questions?

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Supplemental Slides

Recent Parameter Validation

New York State announced sero-prevalence survey results on May 2nd

- 15,000 antibody tests conducted randomly through the state at grocery stores
- **Total Attack Rate**: 12.3%

Estimation of undetected infections

- Total infections in NY = 2.46M, total of 300K confirmed cases
- Confirmed case detection = 12% of infections (close to 15% used in model)

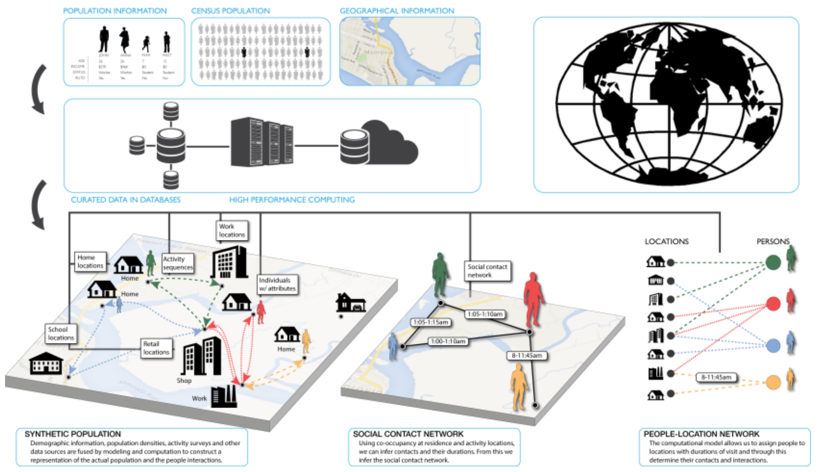
Estimation of hospitalizations from infections

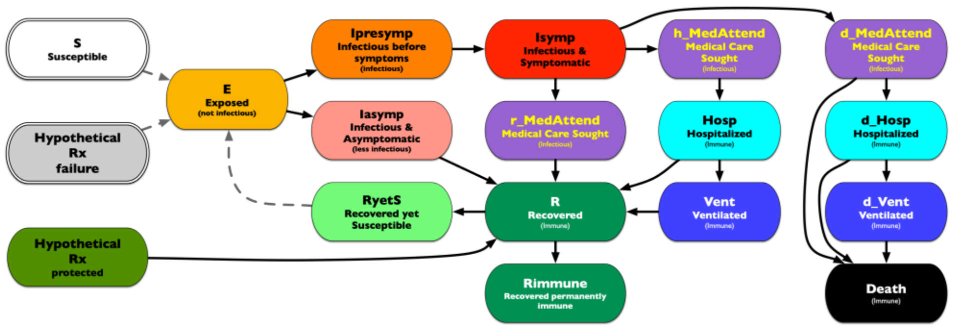
- Total infections in NY = 2.46M, total of 66K hospitalizations
- Hospitalizations = 2.7% of infections (close to 2.25% used in model)

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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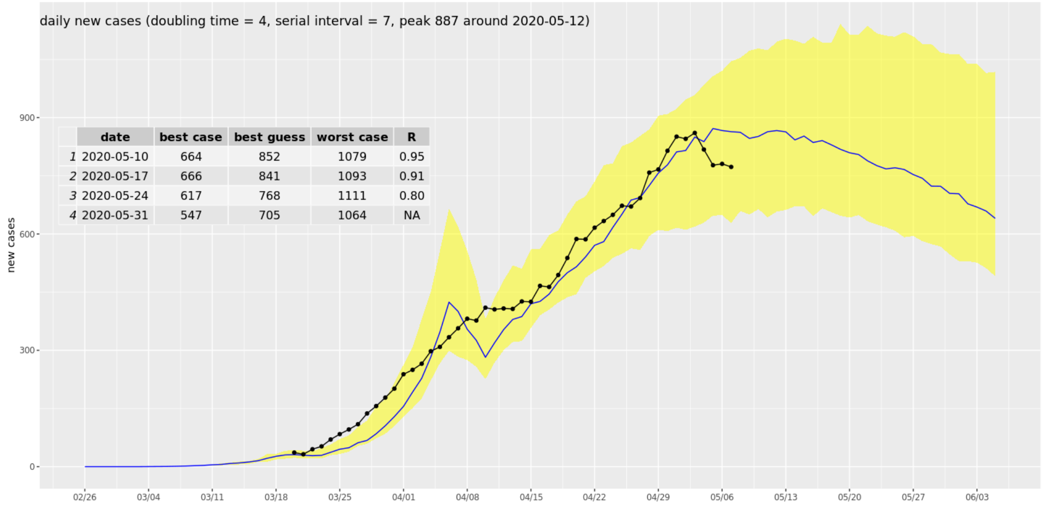
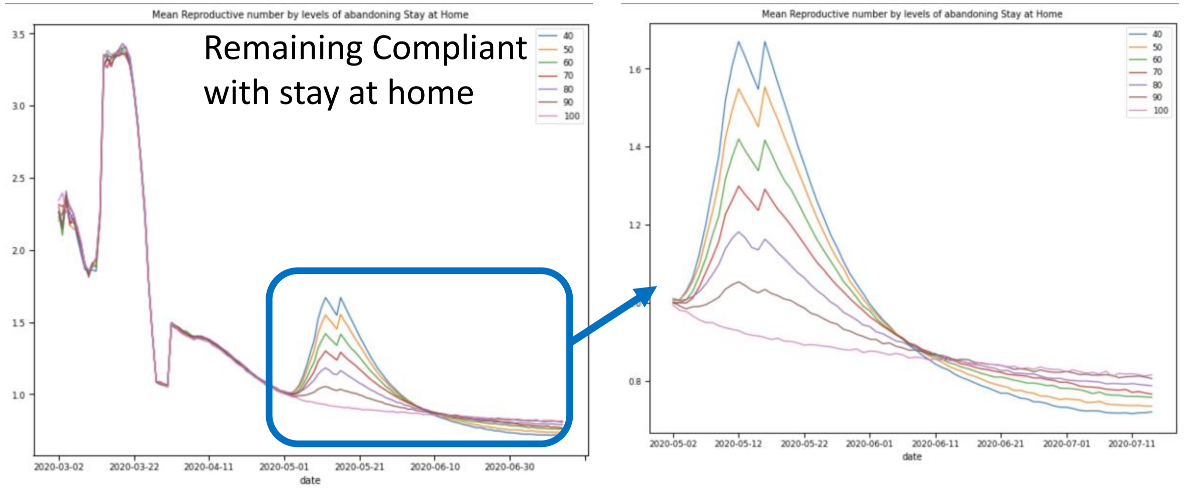
ABM Social Distancing Rebound Study Design

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

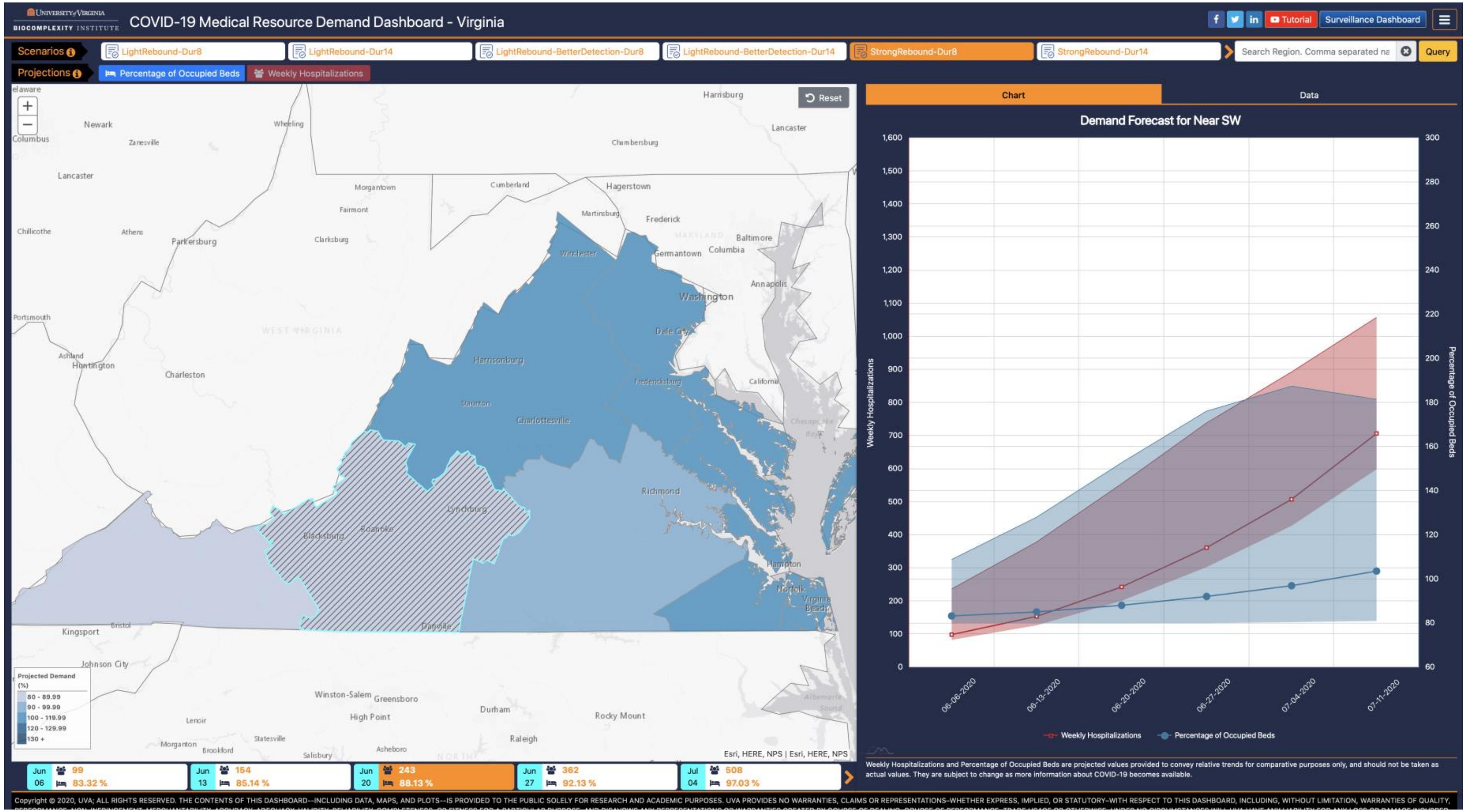
- Adjust transmission and adherence to current policies to current observations
- For Virginia, with same seeding approach as PatchSim

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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