Network Systems
Science & Advanced
Computing

Biocomplexity Institute
& Initiative

University of Virginia

Estimation of COVID-19 Impact in Virginia

June 24th, 2020

(data current to June 23rd)

Biocomplexity Institute Technical report: TR 2020-079

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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

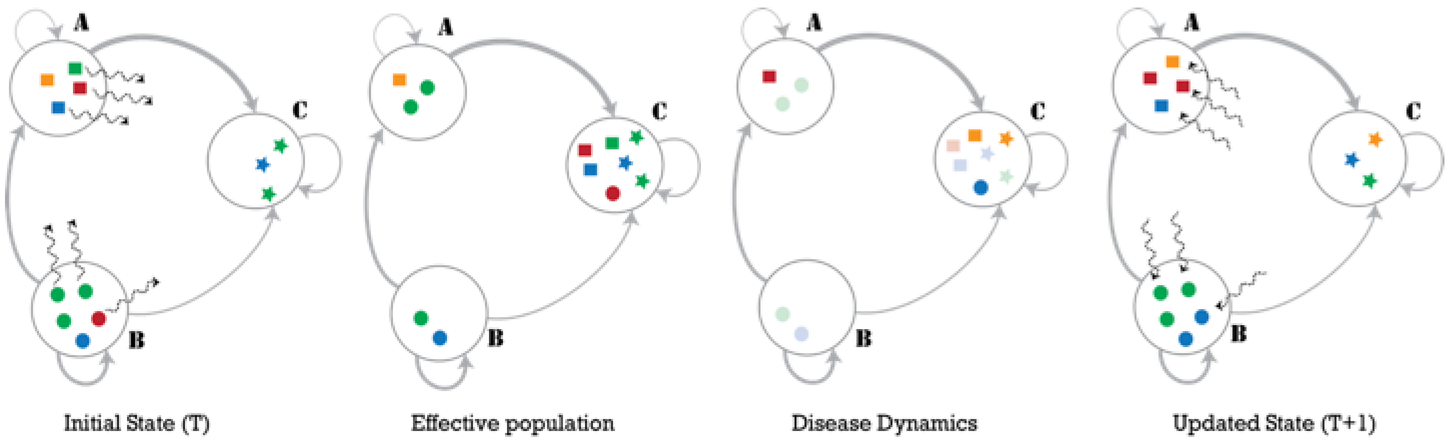
Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

- **We remain in a period of transition, shifting to sustaining control through test and trace and other mitigations rather than strict social distancing.**
- Model updates this week
  - Identified “Best fit” projection by district which matches the recent trends in that district
  - Better calibrated to district level variations across the Commonwealth
  - Altered projection scenarios to capture increased mixing moderated with good infection control practices (decreased risk per interaction)
  - Updated additional analyses to inform restructuring of model for next phase of epidemic
- Impact of better detection and isolation are showing.
- The situation is changing rapidly. Models will be updated regularly.

Model Configuration and Data Analysis

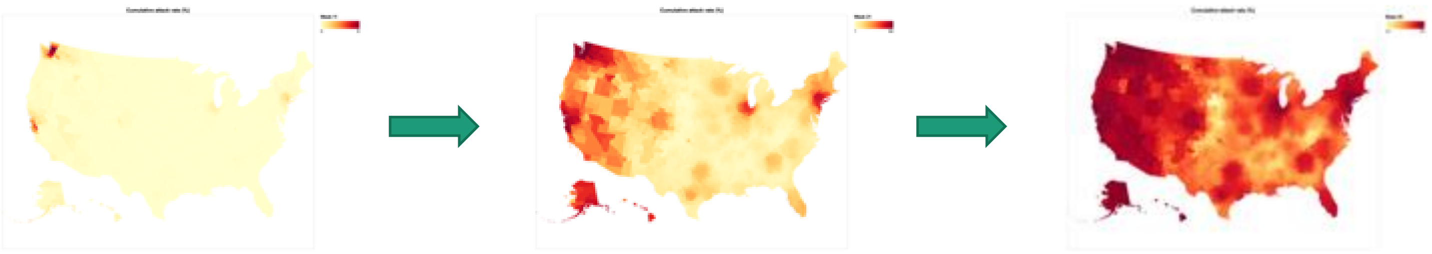
Simulation Engine – PatchSim

- 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

Mitigation Scenarios: Rebound Intensity x Detection

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:

- **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 (30% and then 45%) 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

Five Mitigation Scenarios

Scenario	Rebound Intensity	Better Detection	Name	Description
1	Light	No	Light	Light Rebound, Detection same
2	Steady	No	Steady	Steady Interactions, Detection same
3	Light	Yes	Light – BetterDetection	Light Rebound, Detection improved
4	Steady	Yes	Steady – BetterDetection	Steady Interactions, Detection improved
5	Full	No	Full Rebound	Return to No mitigation

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)

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

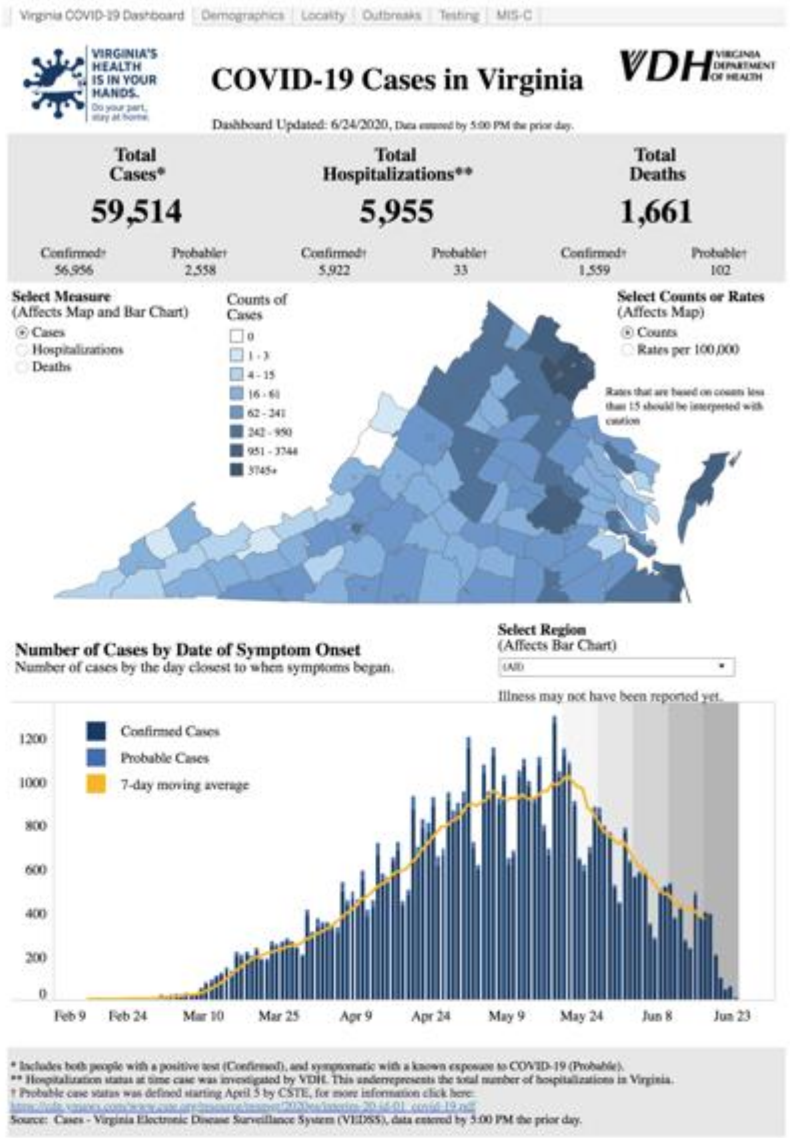
- Total infections in NY = 2.46M, total of 300K confirmed cases
- Confirmed case detection = 12% of infections (close to 15% used in model)

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)

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 9:00am June 24, 2020
https://www.vdh.virginia.gov/coronavirus/

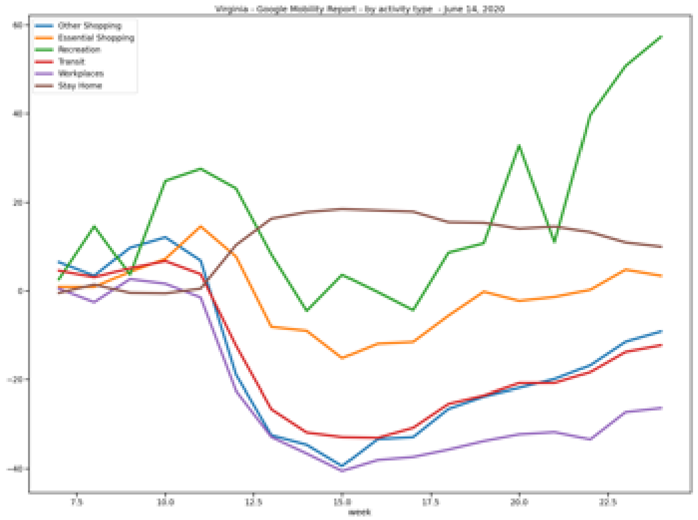
Impact of Interventions

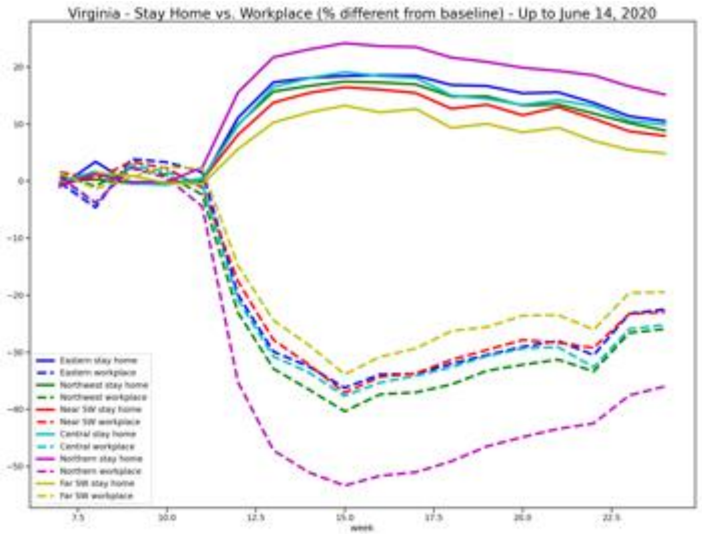
Estimating Effects of Social Distancing

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

Google Mobility data shows continued slow rebound
(as of June 14th)
https://www.google.com/covid19/mobility/

- Regional levels of Stay at home vs. Workplace
- 35% 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



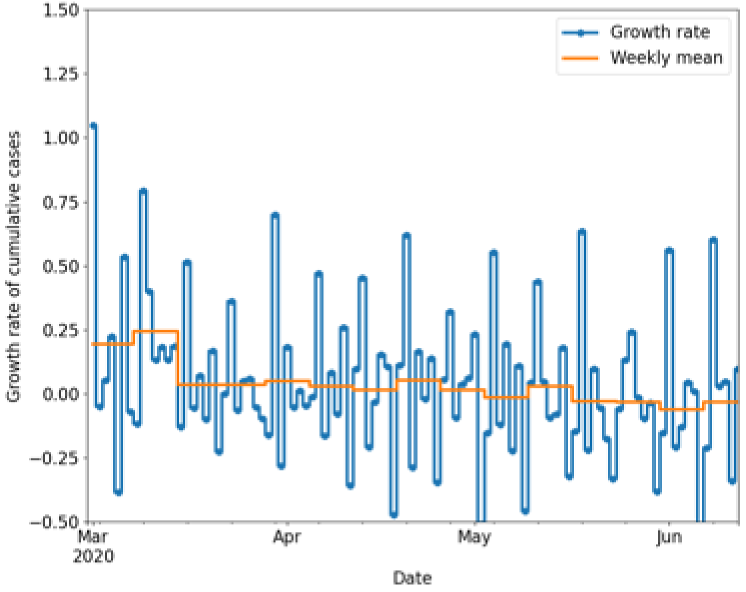


Weekly growth rate by date of onset

- Week before March 15 = 0.3
- Week after March 15 = -0.03 to 0.04

Crude reproductive number estimates

- 2.2 before March 15th
- 0.81 to 1.10 after March 15th



Estimating Effects of Better Detection

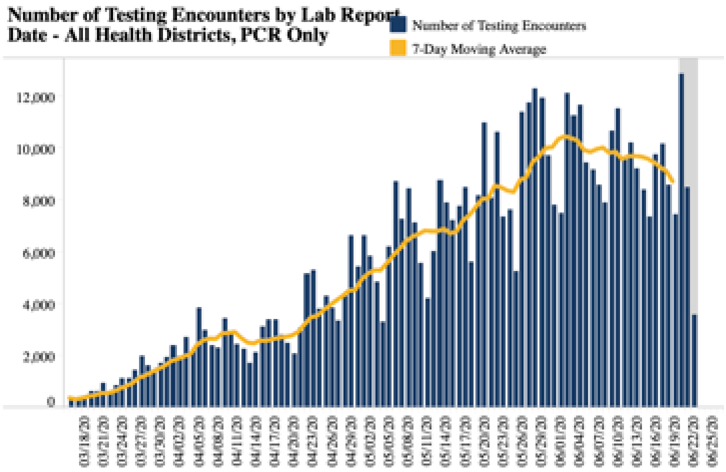
VDH data shows reductions in time from Symptom Onset to Diagnosis

Days to Diagnosis drops ~30% in recent weeks

- Mid March to Late April = 7.8 days
- Late April to Mid May = 5.5 days (30% lower)
- Mid May to end of May = 4.5 days (45% lower)
- Minimal shifts from last week (7.9, 5.5, and 4.4)

Testing Encounters increased, though slowing:

~30K/week (late April) to ~8K/day (early June)



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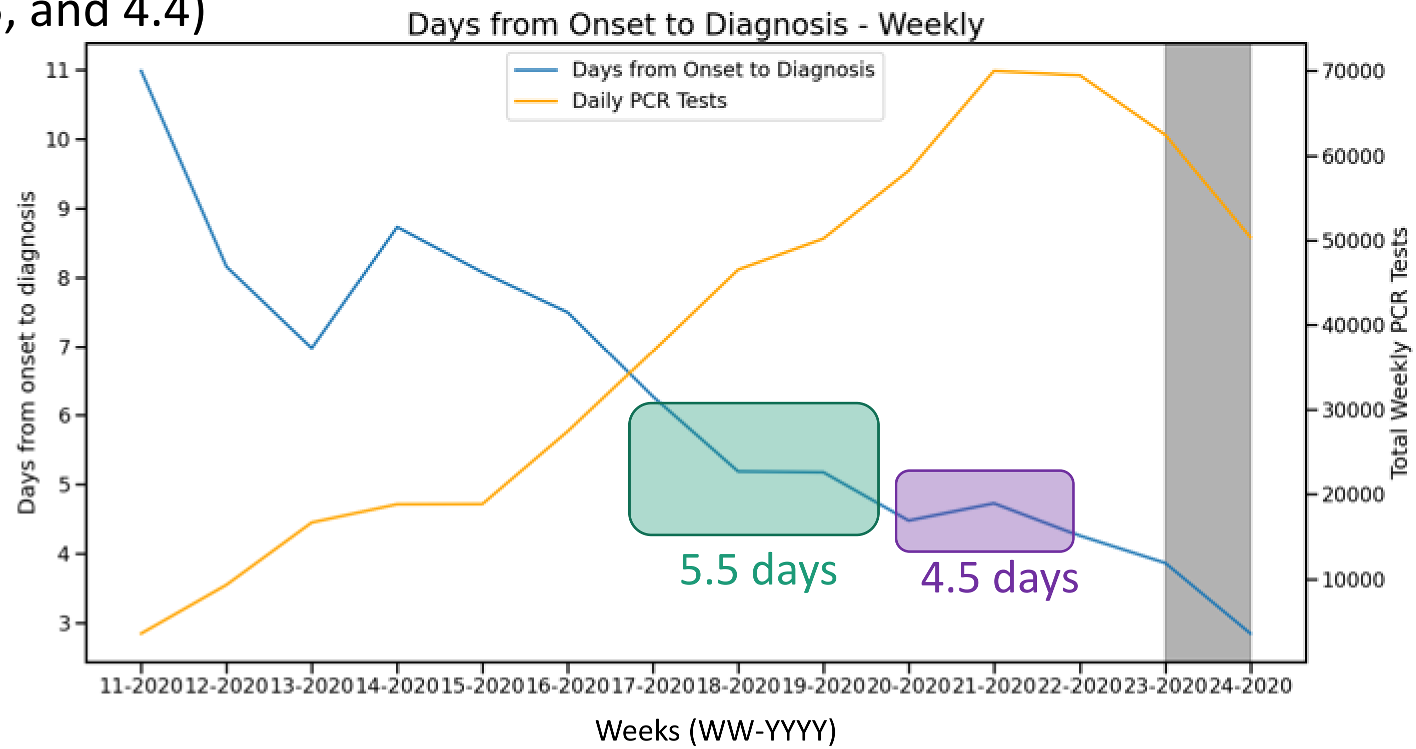
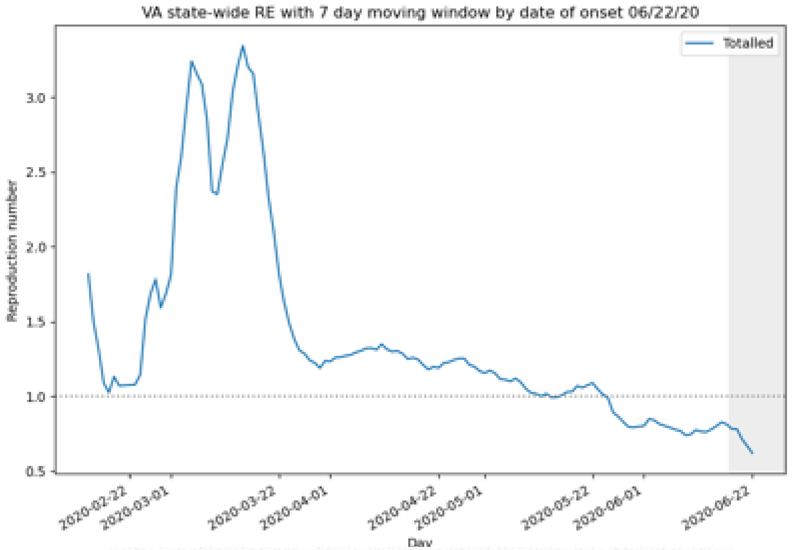
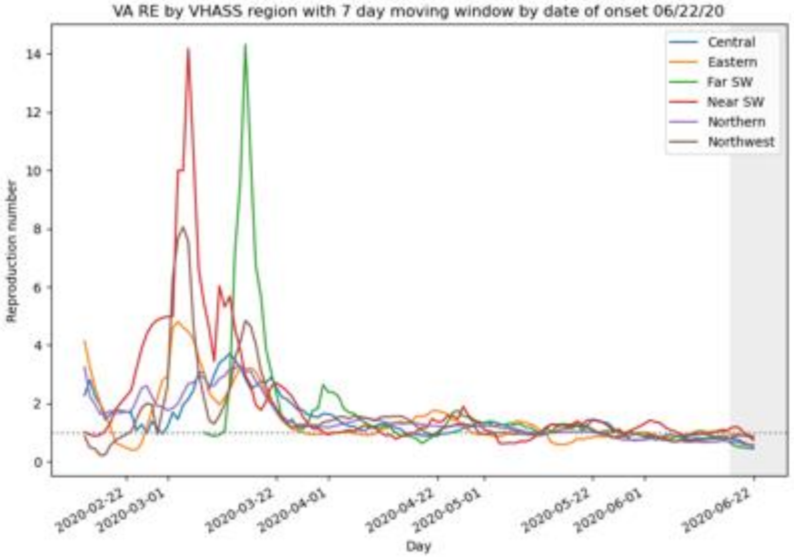


Estimating Daily Reproductive Number





Statewide and most regions follow similar pattern

- Spike, followed by a decline, to plateau, with recent upswing
- This week: overall decline, some regions up

Methodology

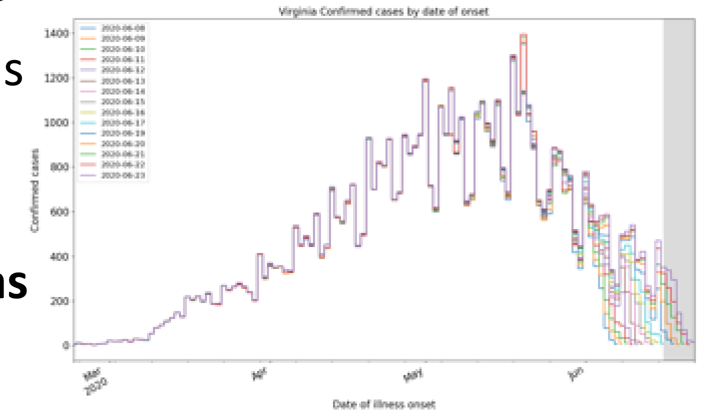
- Wallinga-Teunis method as implemented in EpiEstim[1] R package
- Based on Date of Onset of Symptoms
- Uses serial interval to estimate R_e over time: 6 days (2 day std dev)

Recent Estimates subject to revision as more data comes in

- Date of onset unstable in last 7-14 days

June 13th Estimates

Region	Current R_e	Diff Last Week
State-wide	0.759	0.032
Central	0.795	-0.033
Eastern	1.023	0.167
Far SW	0.905	0.269
Near SW	0.967	-0.067
Northern	0.661	0.000
Northwest	0.766	0.105

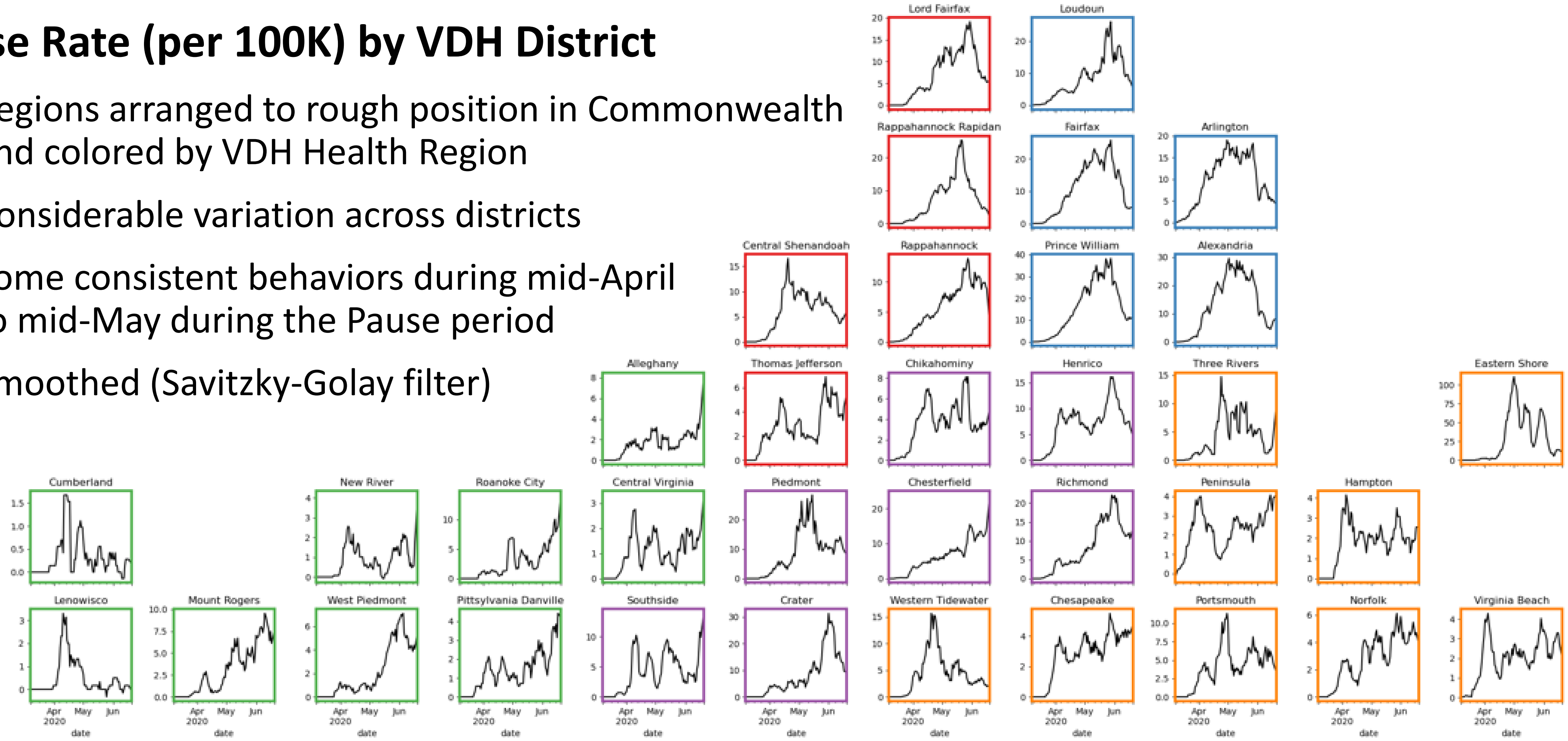


1. Anne Cori, Neil M. Ferguson, Christophe Fraser, Simon Cauchemez. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. American Journal of Epidemiology, Volume 178, Issue 9, 1 November 2013, Pages 1505–1512, https://doi.org/10.1093/aje/kwt133

Spatial Adjustments at District Level

Case Rate (per 100K) by VDH District

- 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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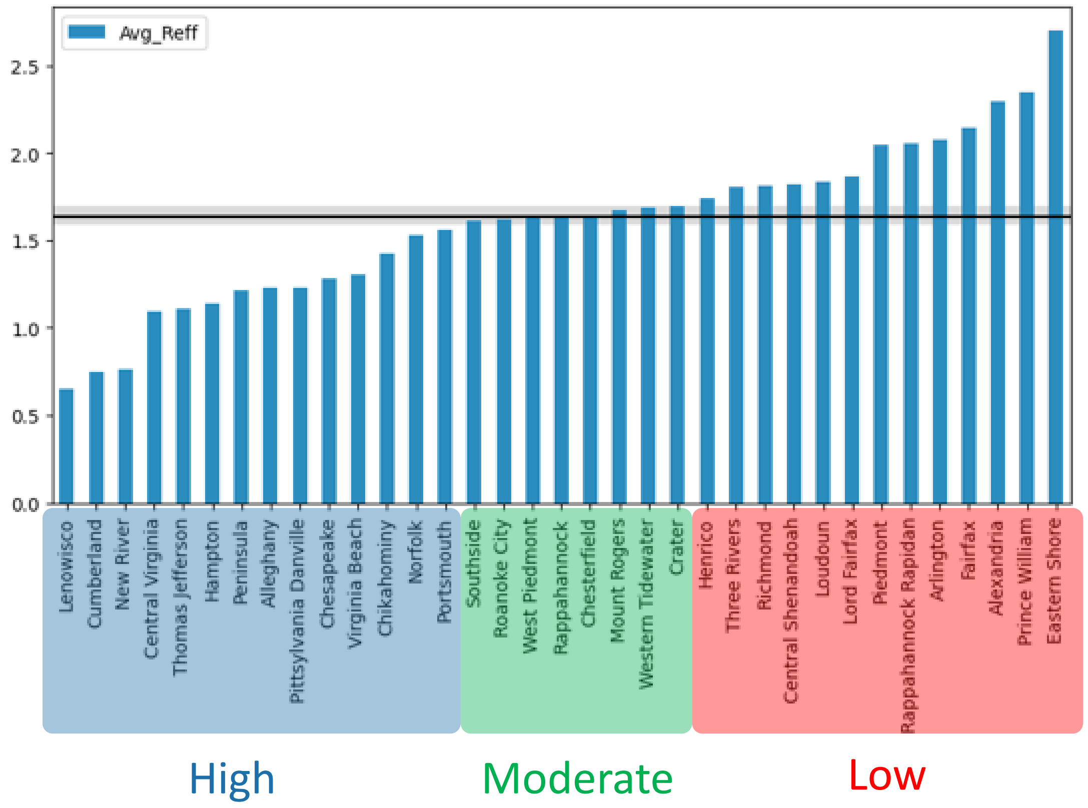
Spatial Adjustments at District Level

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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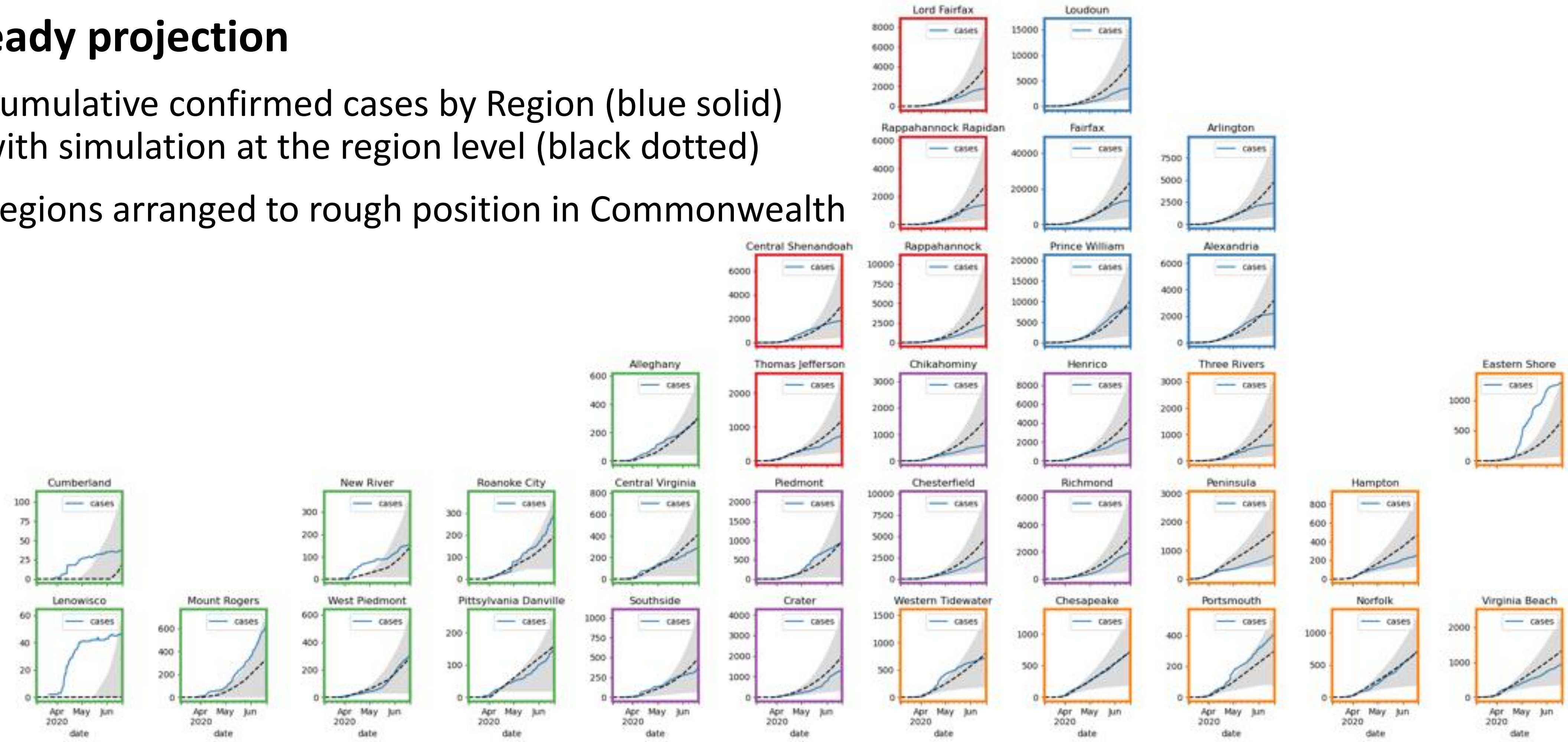
Spatial Adjustments at District Level - Cumulative

Steady projection

- Cumulative confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Regions arranged to rough position in Commonwealth



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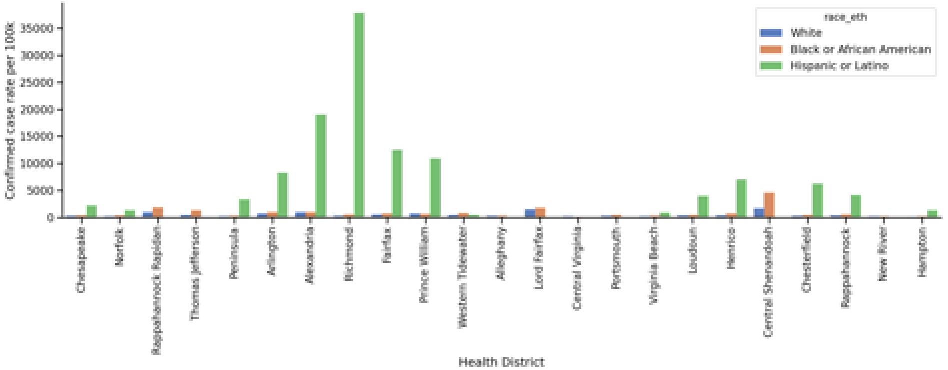
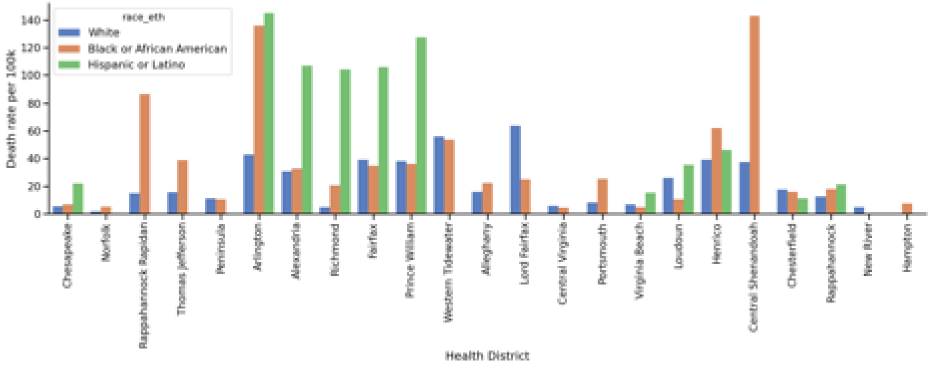
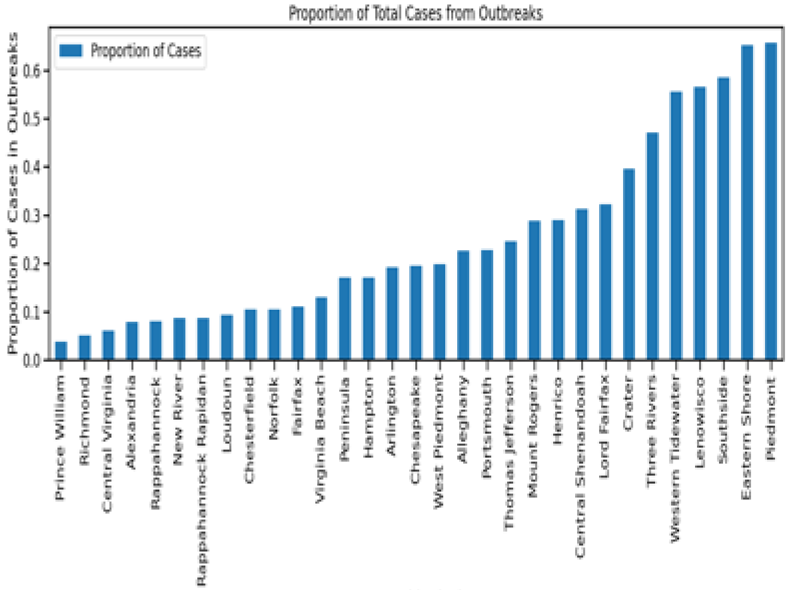
Impact of Race / Ethnicity & Outbreaks

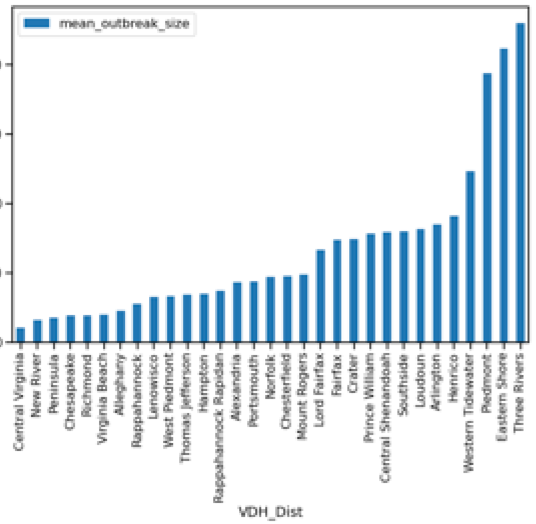
Confirmed Case Rate



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

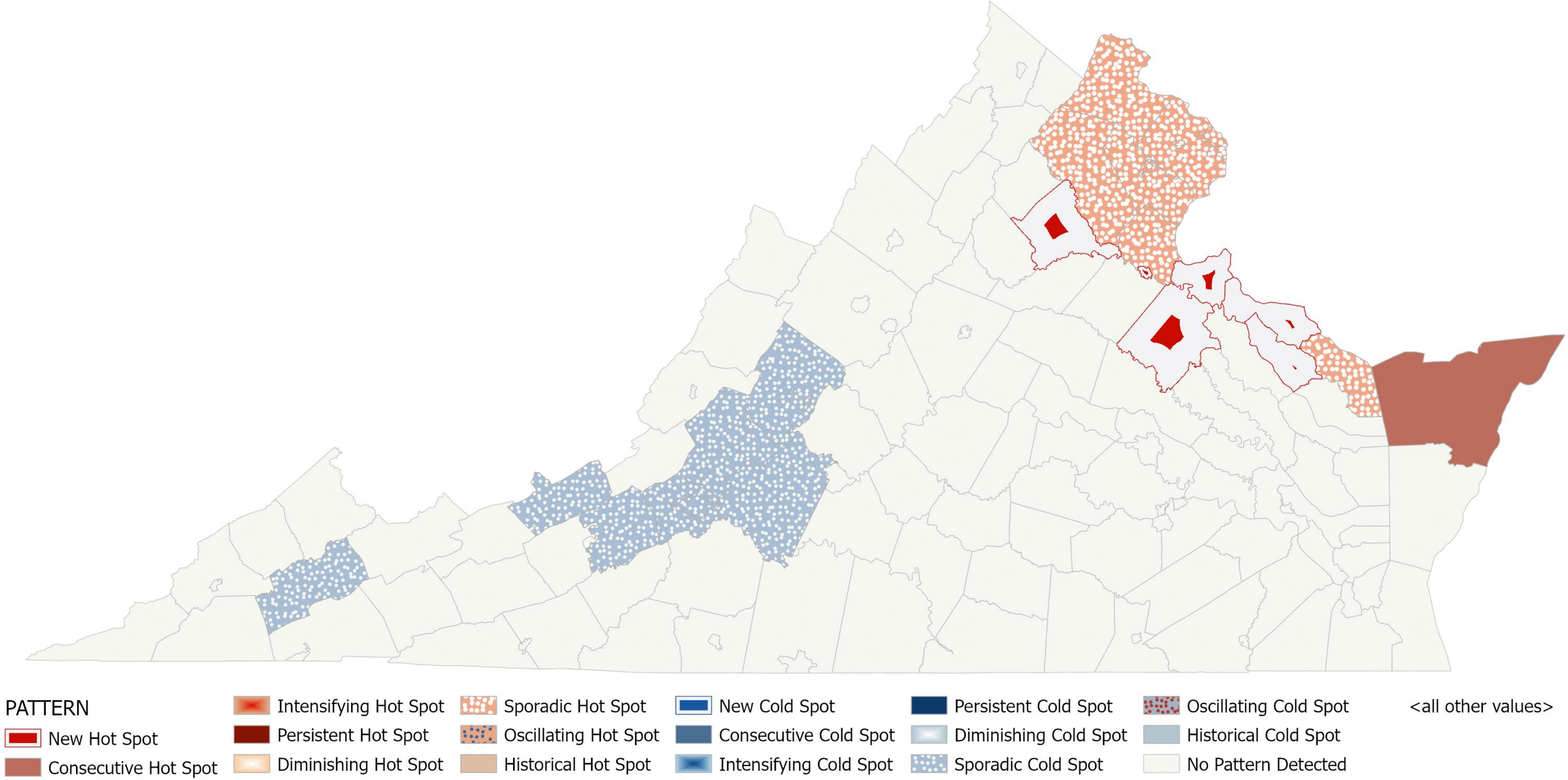
- Eastern Shore has 60% of cases from 10 outbreaks
- Fairfax most outbreaks but relatively low proportion

Emerging Hot Spot Analysis

No Pattern Detected	No significant patterns.
New Hot Spot	Hot spot for final timestep, never significant before.
Consecutive Hot Spot	Single uninterrupted run of significant hot spot scores.
Intensifying Hot Spot	Significant hot spot for 90% of time, clustering increasing.
Persistent Hot Spot	Significant hot spot for 90% time, no change in clustering.
Diminishing Hot Spot	Significant hot spot for 90% of time, clustering decreasing.
Sporadic Hot Spot	On-again then off-again hot spot.
Oscillating Hot Spot	Hot spot in final step, history of being significant cold spot.
Historical Hot Spot	No longer hot spot but was for 90% of time.

- Runs a Hot Spot Analysis at each time step
- Then a Mann Kendall Test on each county to detect temporal trends
- As with standard analysis, output is based on significance of clusters, not absolute values

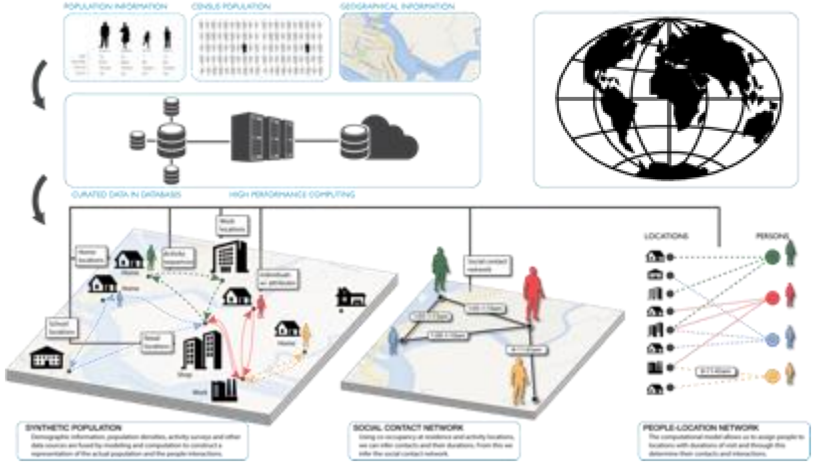
Emerging Hot Spot Analysis for COVID19 Incidence
2020-03-01 to 2020-05-16 (weekly)



Agent-based Model (ABM)

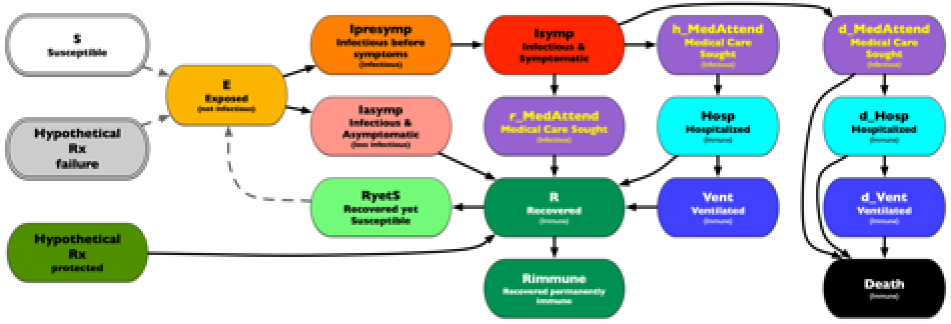
EpiHiper: Distributed network-based stochastic disease transmission simulations

- 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



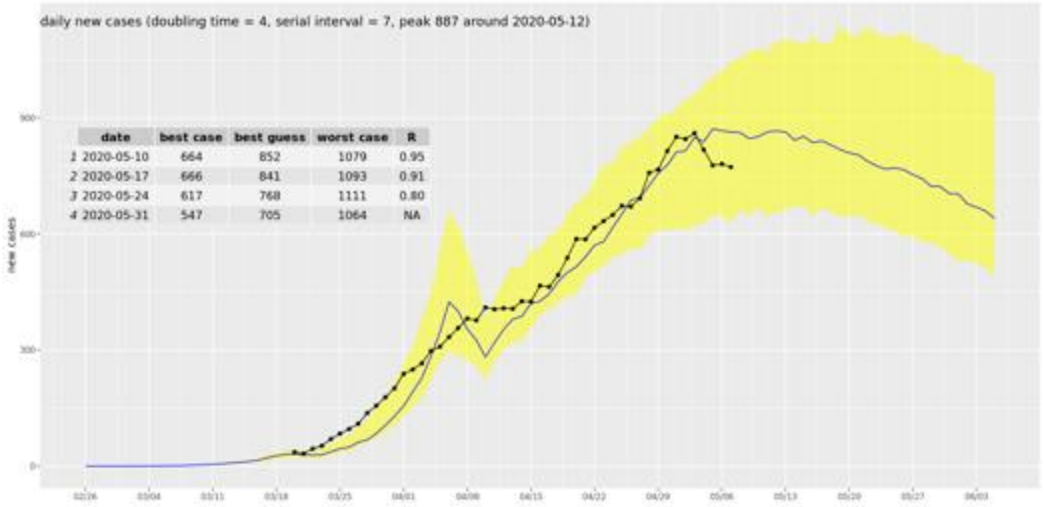
Detailed Disease Course of COVID-19

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

ABM Social Distancing Rebound Study Design

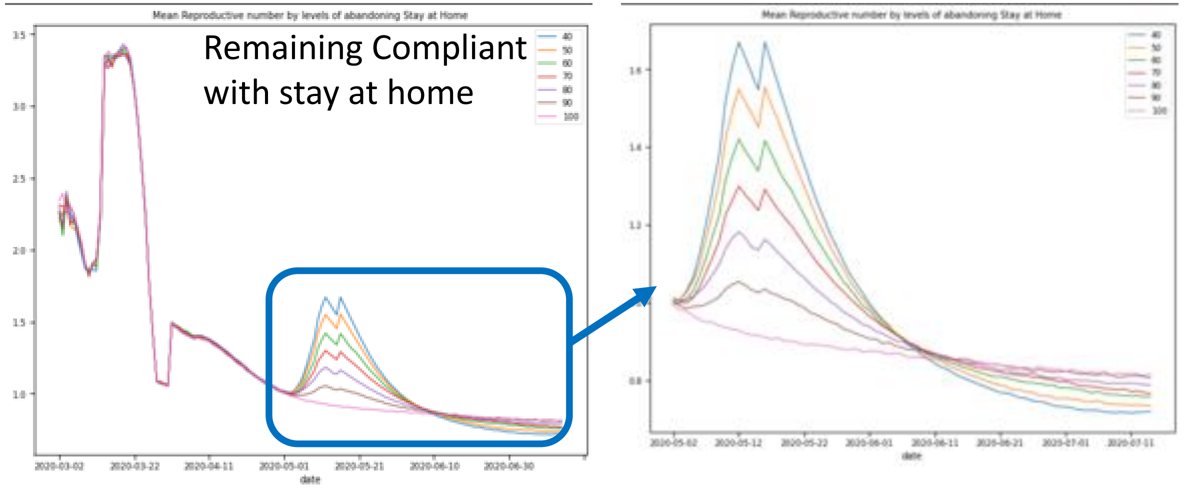
Study of ”Stay Home” policy adherence

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



Calibration to Current State

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

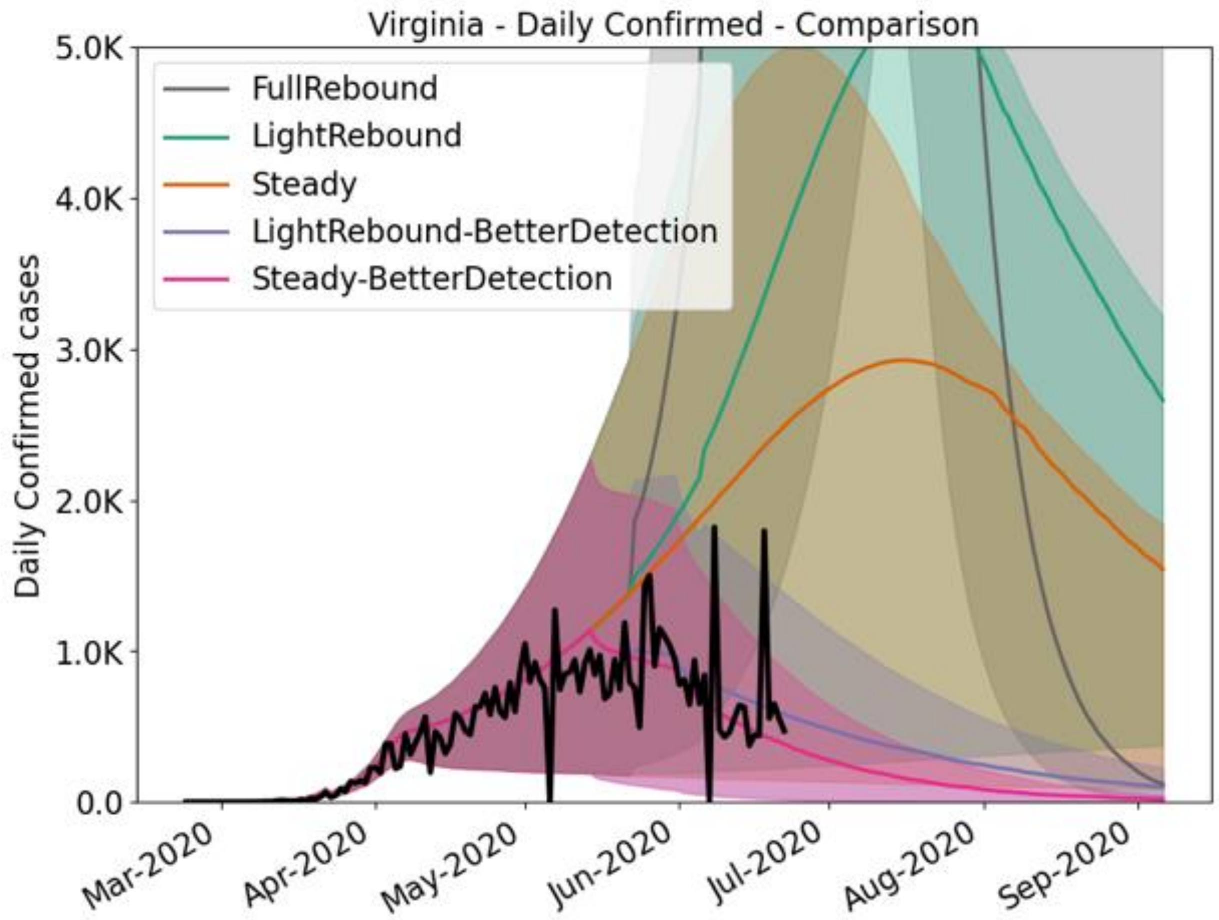


Impacts on Reproductive number with release

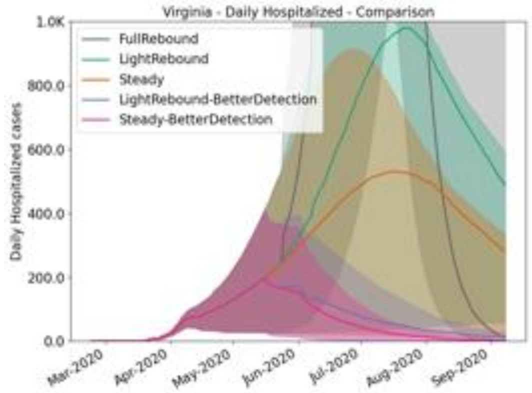
- After release, spike in transmission driven by additional interactions at work, retail, and other
- At 25% release (70-80% remain compliant)
- Translates to 15% increase in transmission, which represents a 1/6th return to pre-pandemic levels

Outcome Projections

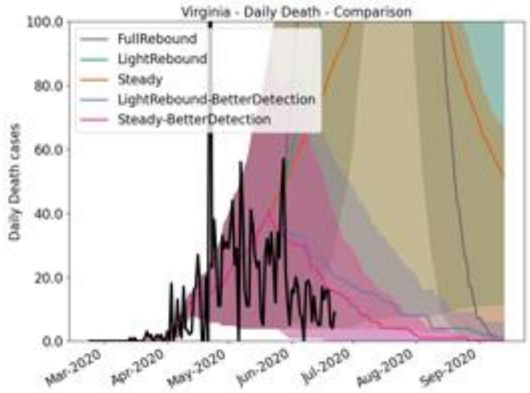
Confirmed cases



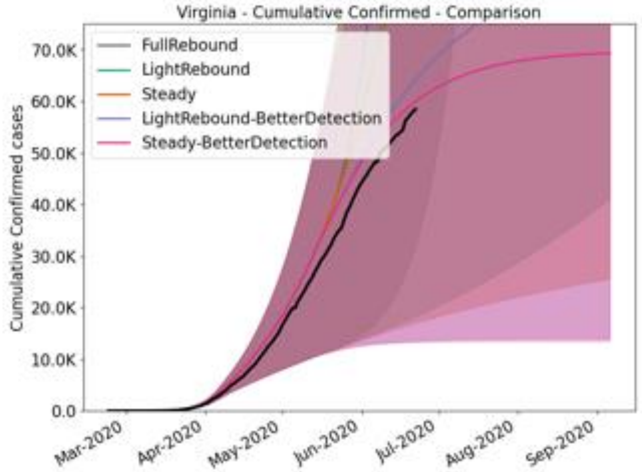
Hospitalizations



Deaths



Cumulative Confirmed cases



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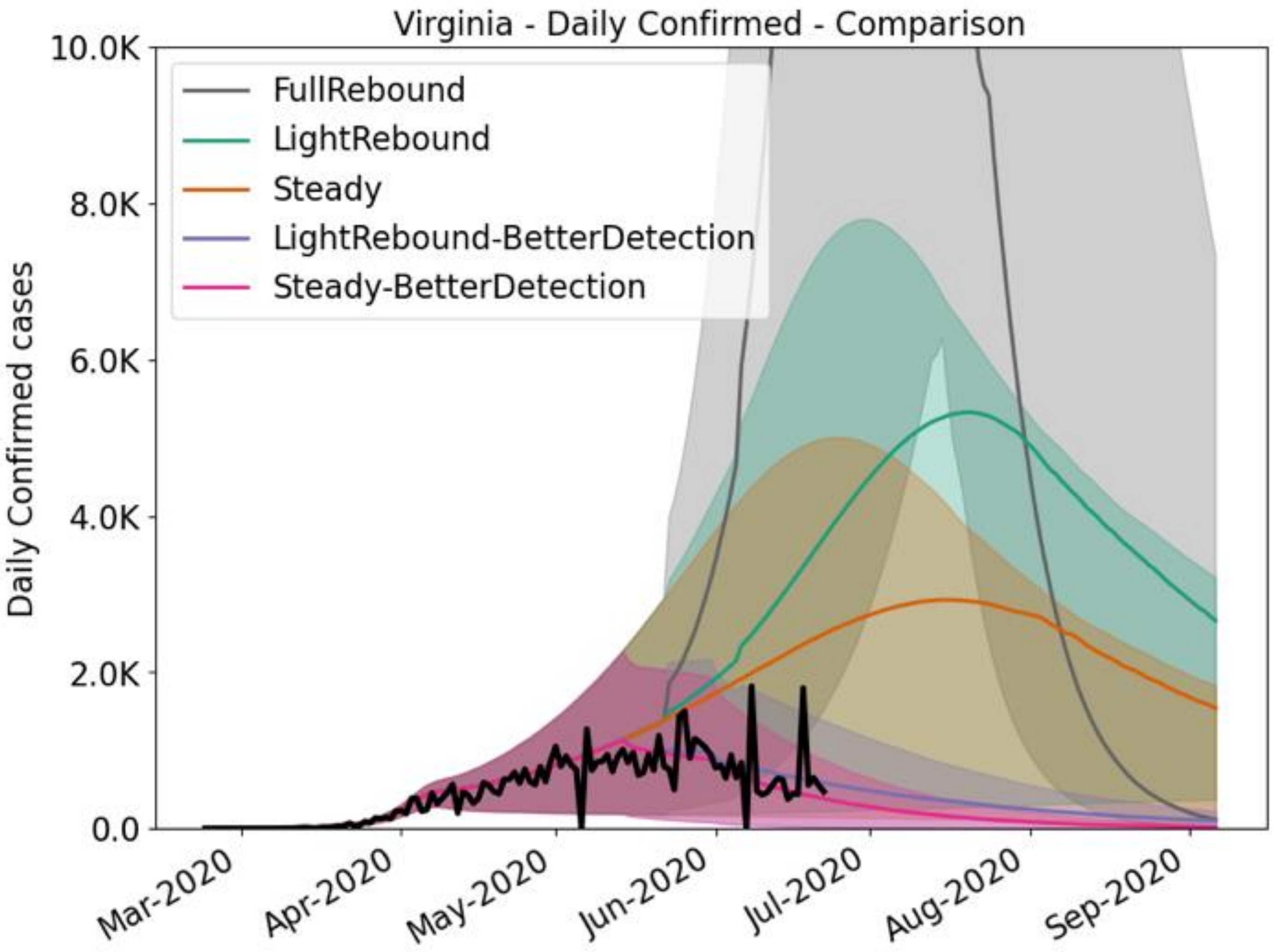
Period of Transition: Sustaining Control



Weekly New Confirmed Cases*

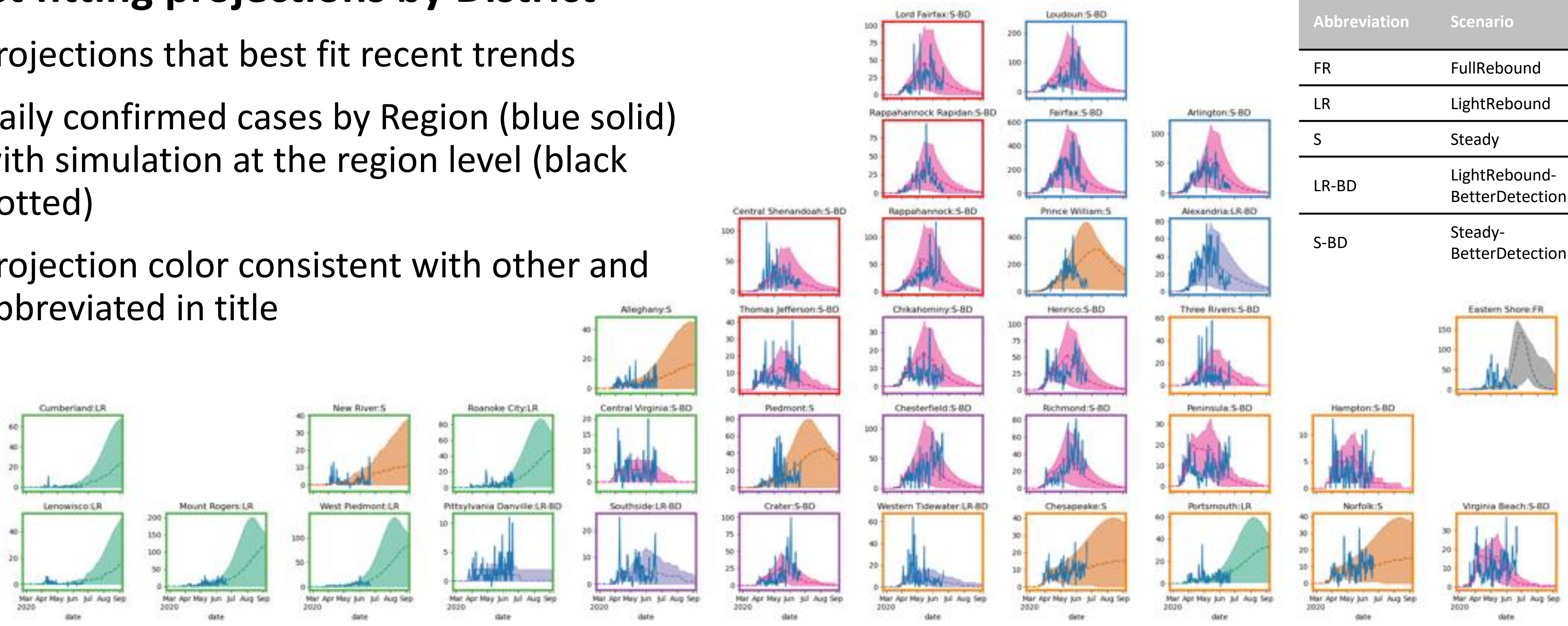
Week Ending	Light Rebound	Steady	Steady – Better Detection
6/14/20	17,974	14,174	4,160
6/21/20	22,176	15,971	3,287
6/28/20	26,682	17,632	2,591
7/5/20	30,920	18,968	2,008
7/12/20	34,380	19,946	1,544
7/19/20	36,014	20,388	1,204
7/26/20	35,582	20,050	918
8/2/20	33,601	19,000	690
8/9/20	31,140	17,698	514
8/16/20	28,336	16,214	386
8/23/20	25,642	14,614	298
8/30/20	22,742	12,980	228

*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



Abbreviation	Scenario	# of Districts
FR	FullRebound	1
LR	LightRebound	6
S	Steady	6
LR-BD	LightRebound-BetterDetection	4
S-BD	Steady-BetterDetection	18

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District Level Projections - Cumulative

Best fitting projections by District

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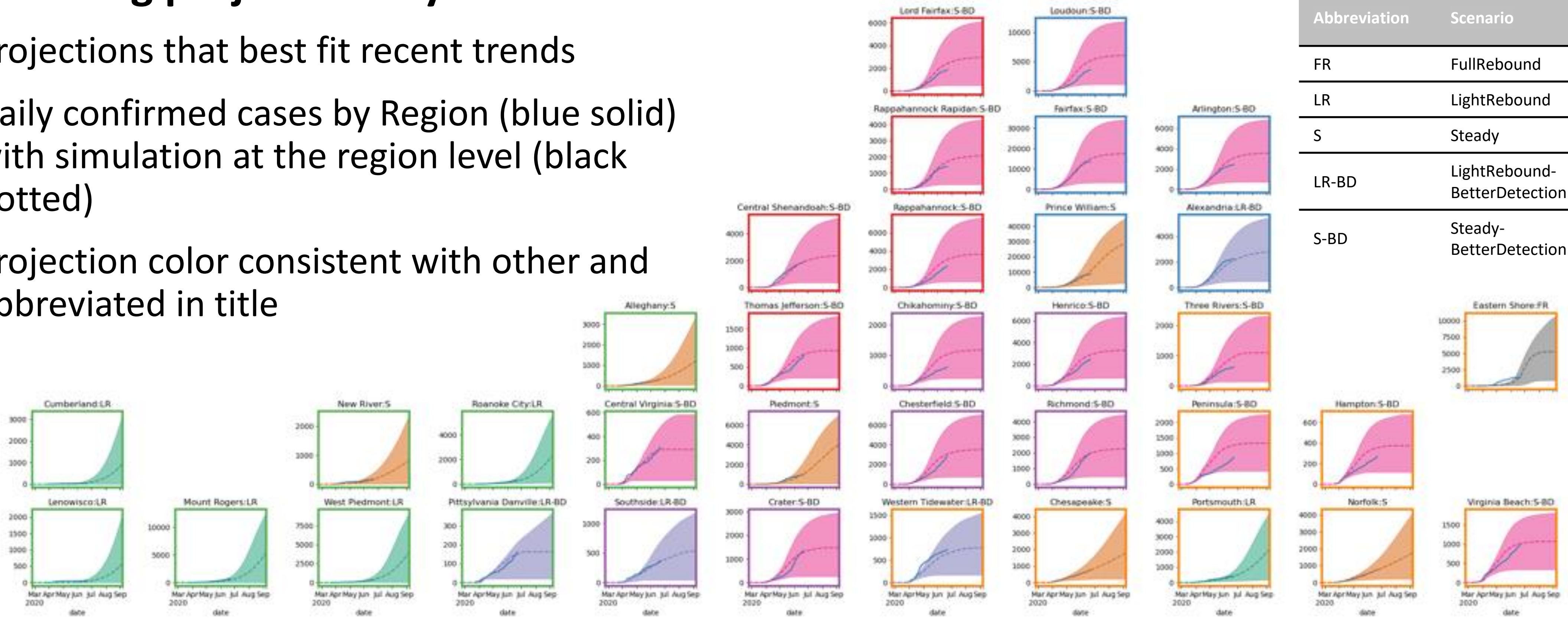

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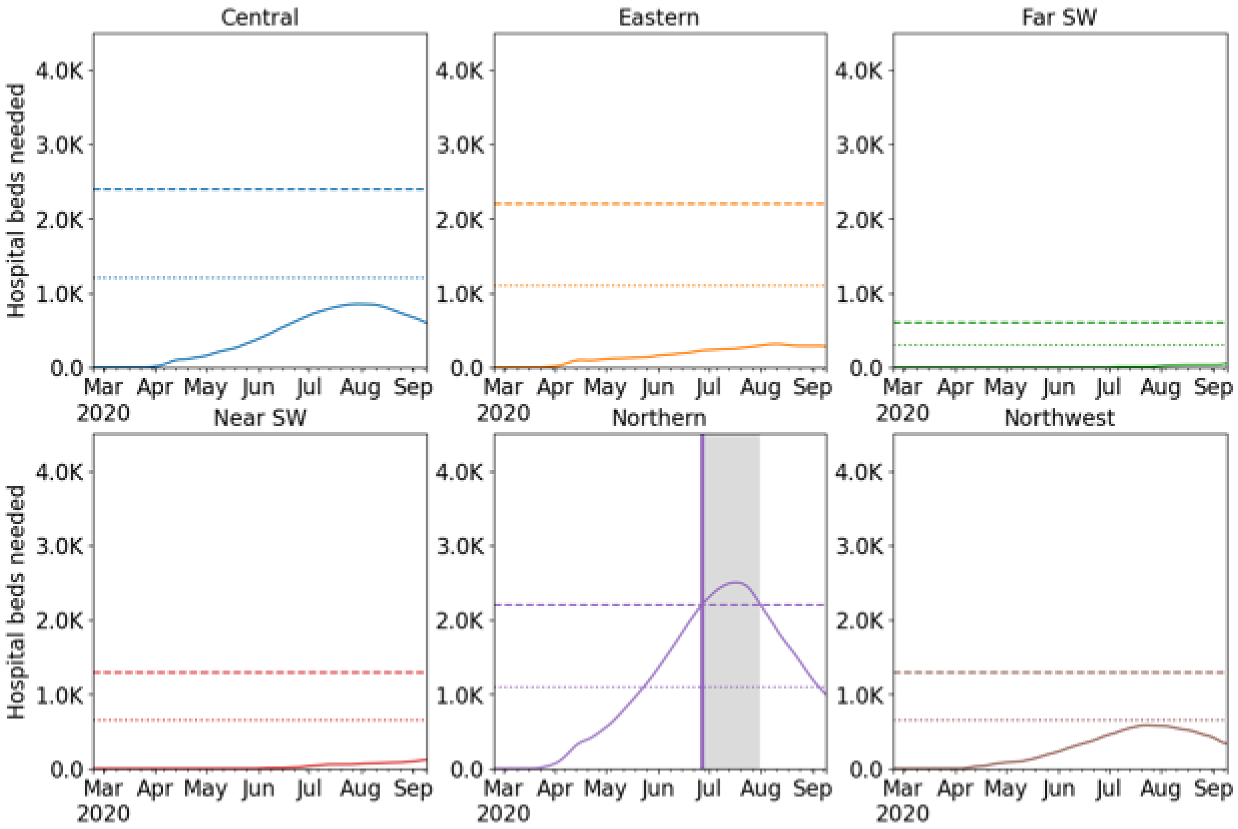
Hospital Demand and Capacity by Region

Capacities by Region – Steady

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



* Assumes average length of stay of 8 days

Date ranges when regions are estimated to exceed surge capacity

	Scenario	Date Ranges
1	Light	Mid June to Mid Aug
2	Steady	Late June to Late July
3	Light – Better Detection	None
4	Steady – Better Detection	None
5	Full Rebound	Mid June to Early August

Social Distancing postponed the time to when capacity could be exceeded, but without other measures we may still reach it in some areas

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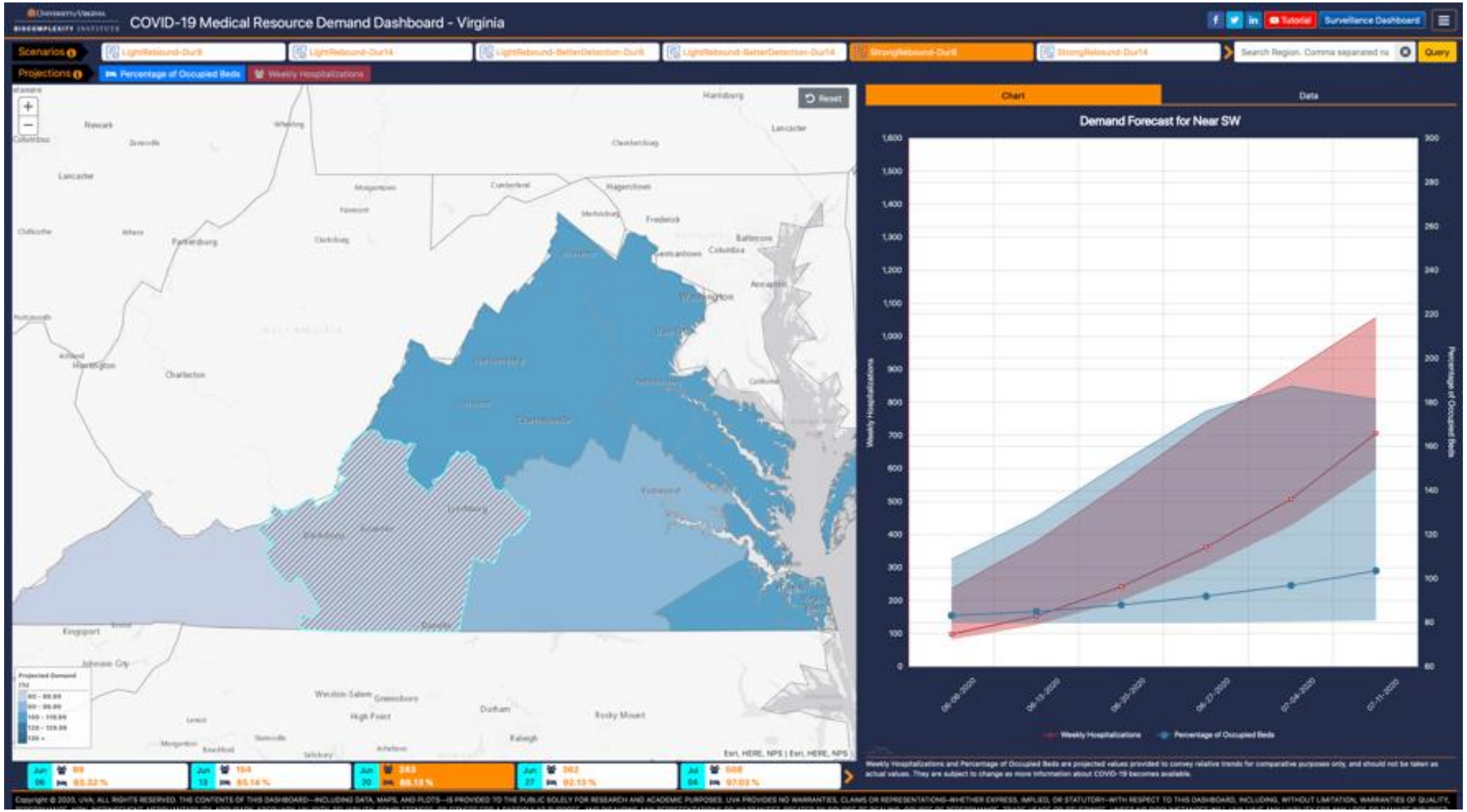
Medical Resource Demand Dashboard

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:

- **We remain in a period of transition, shifting to sustaining control through test and trace and other mitigations rather than strict social distancing.**
- Model updates this week
  - Identified "Best fit" projection by district which matches the recent trends in that district
  - Better calibrated to district level variations across the Commonwealth
  - Altered projection scenarios to capture increased mixing moderated with good infection control practices (decreased risk per interaction)
  - Updated additional analyses to inform restructuring of model for next phase of epidemic
- Impact of better detection and isolation are showing.
- The situation is changing rapidly. Models will be updated regularly.

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