Network Systems Science & Advanced Computing

Biocomplexity Institute & Initiative

University of Virginia

Estimation of COVID-19 Impact in Virginia

June 17th, 2020

(data current to June 16th)

Biocomplexity Institute Technical report: TR 2020-075

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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

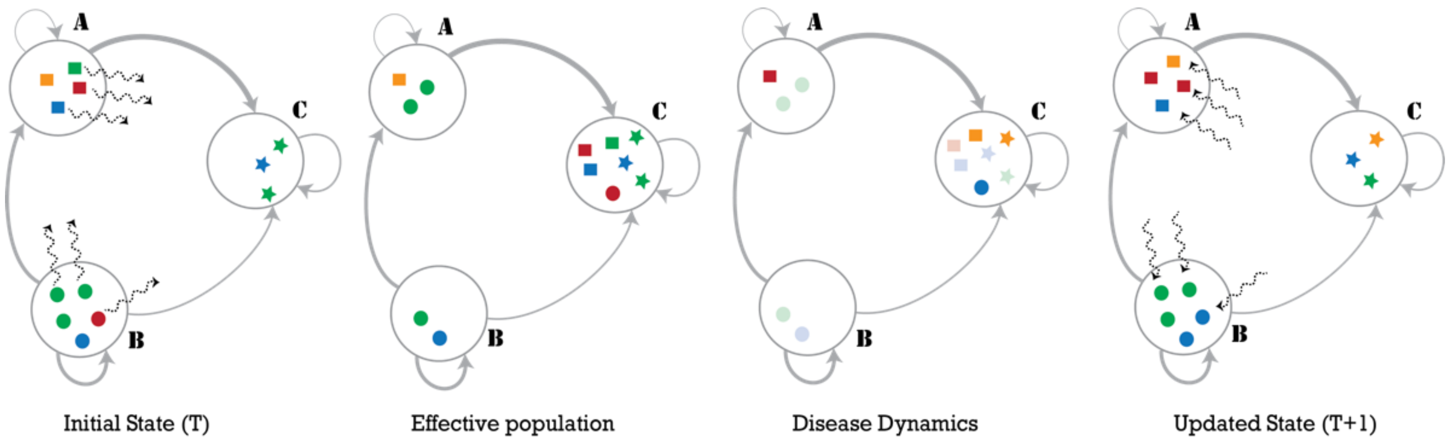
Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

- **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
  - 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)
  - 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

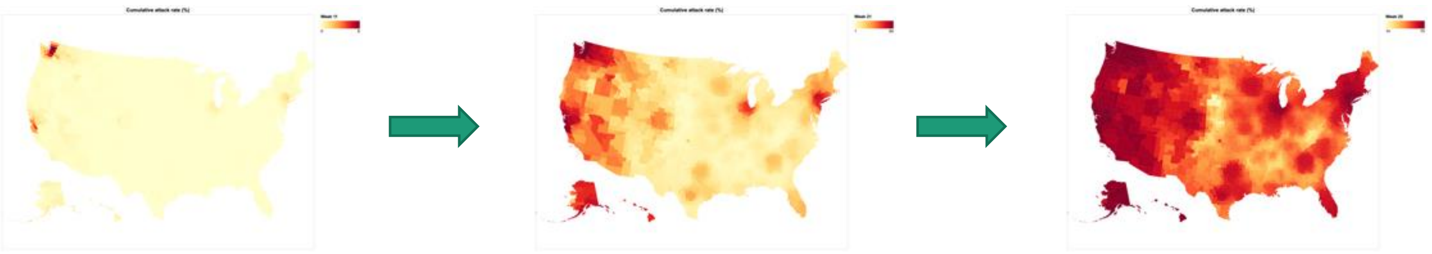
Simulation Engine – PatchSim

- 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 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

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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	1.75%	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

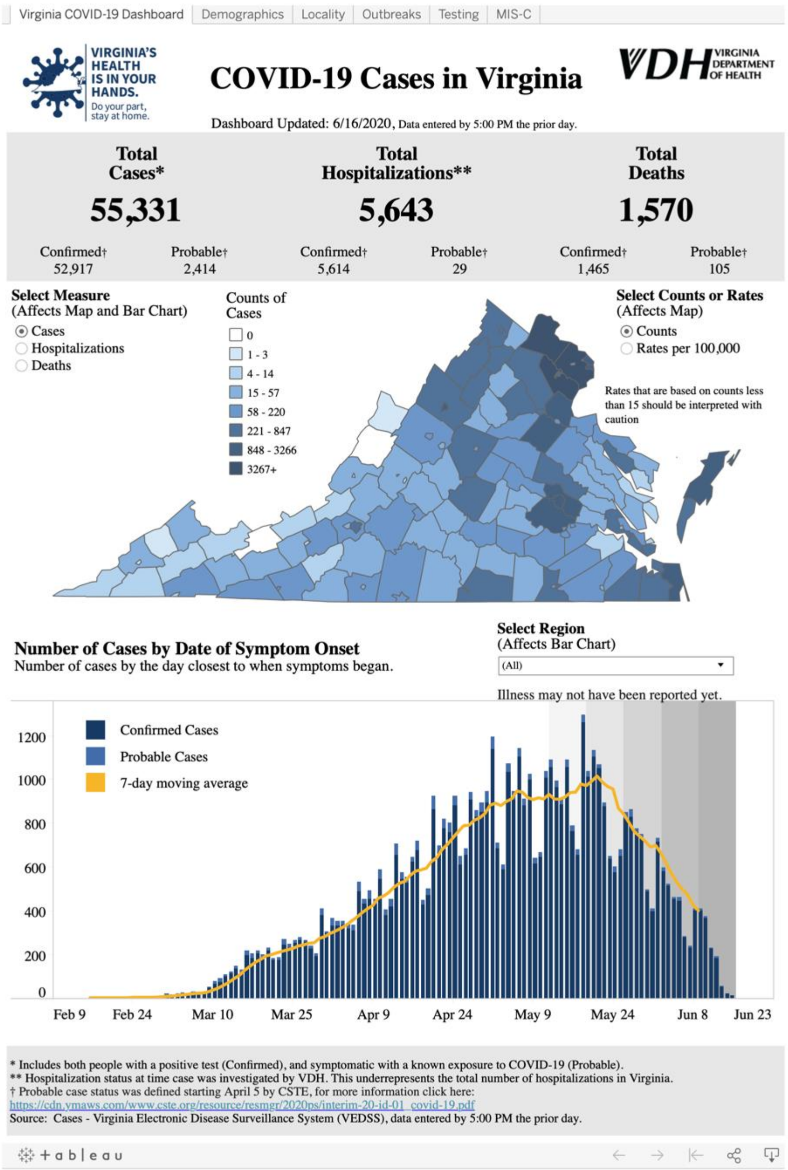
- Total infections in NY = 2.46M, total of 300K confirmed cases
- Confirmed case detection = 12% of infections (close to 15% used in model)

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 5pm June 16, 2020
https://www.vdh.virginia.gov/coronavirus/

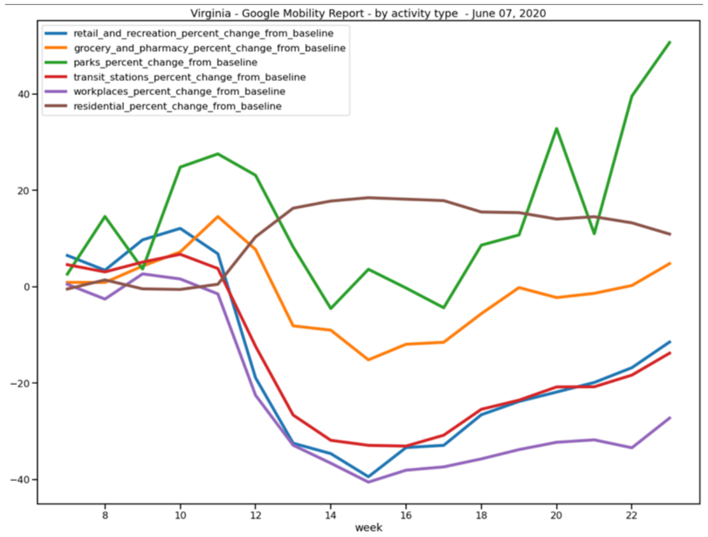
Impact of Interventions

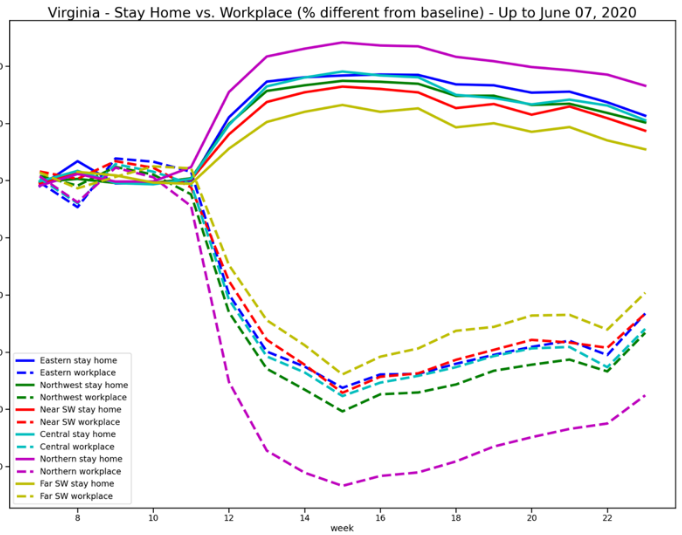
Estimating Effects of Social Distancing

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

Google Mobility data shows continued slow rebound
(as of June 7th)
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



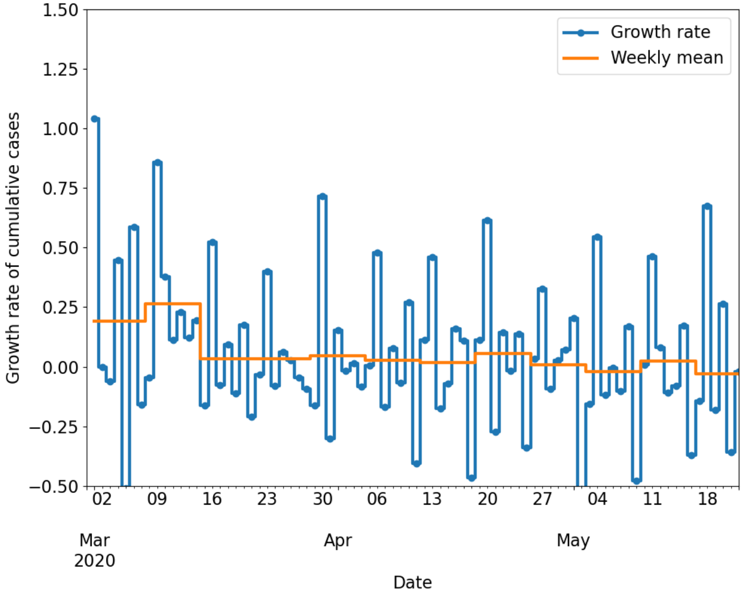


Weekly growth rate by date of onset

- 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

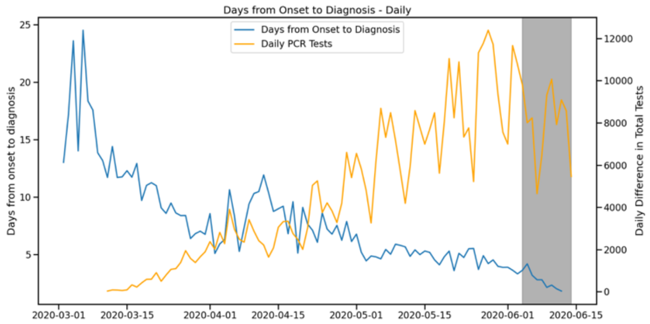


Estimating Effects of Better Detection

VDH data shows reductions in time from Symptom Onset to Diagnosis

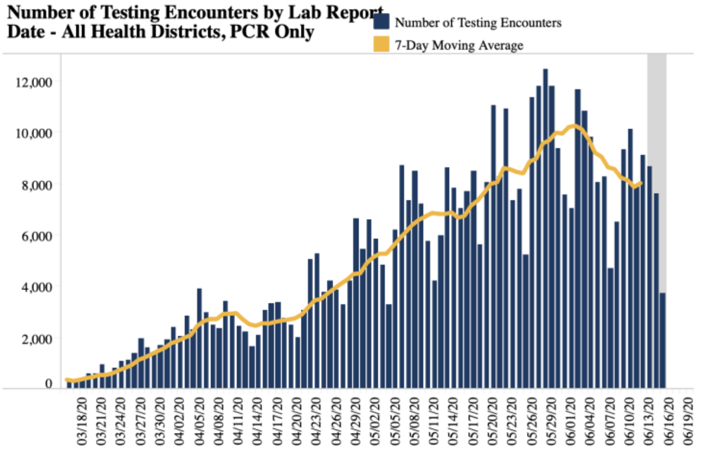
Days to Diagnosis drops ~30% in recent weeks

- Mid March to Late April = 7.9 days
- Late April to Mid May = 5.5 days (30% lower)
- Mid May to end of May = 4.4 days (45% lower)
- Slight shift up from last week (7.5, 5.3, and 4.0)



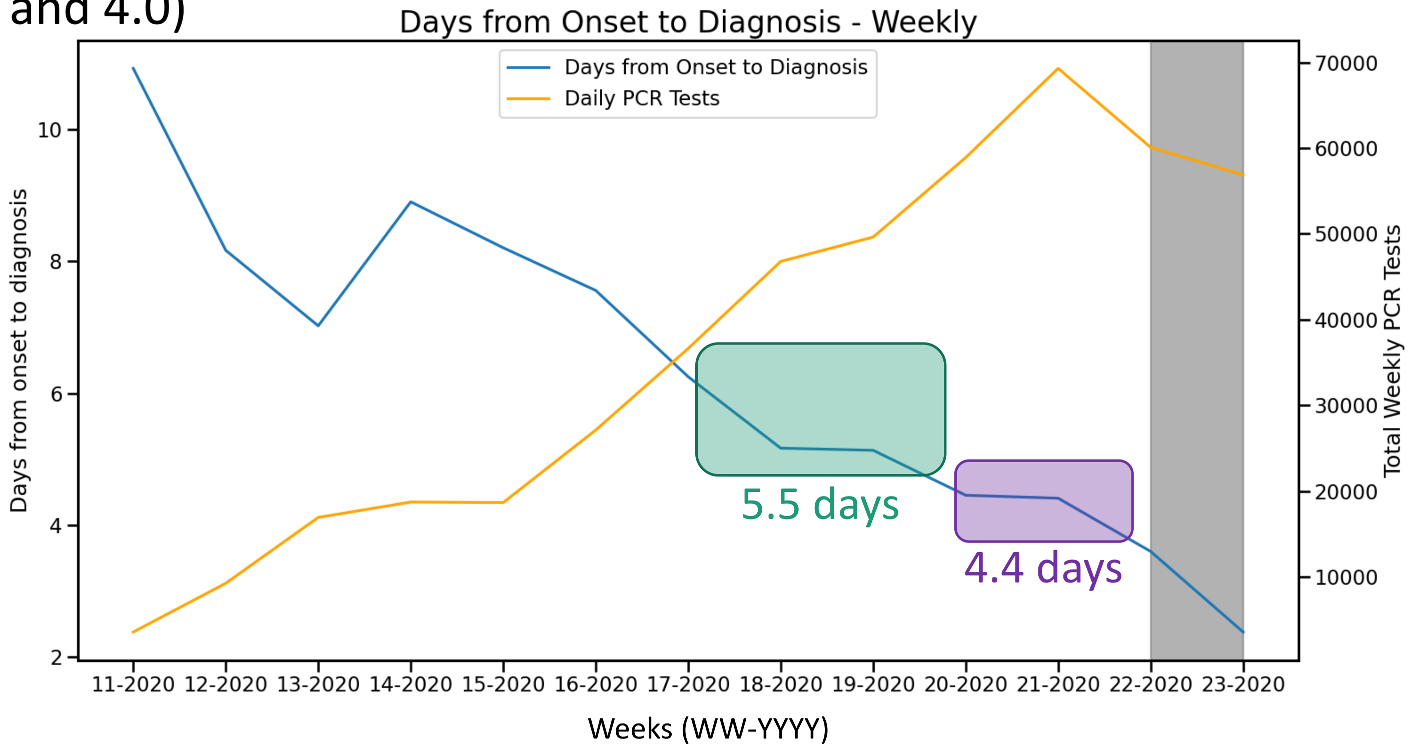
Testing Encounters increased, though slowing:

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

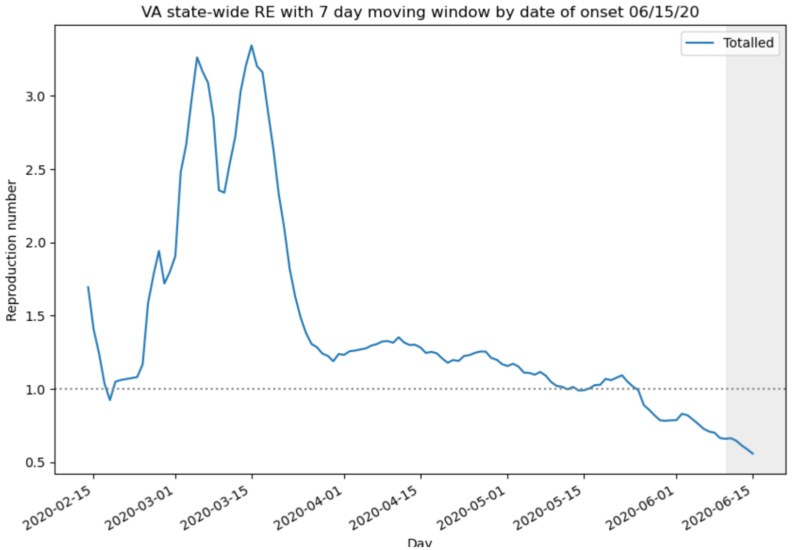


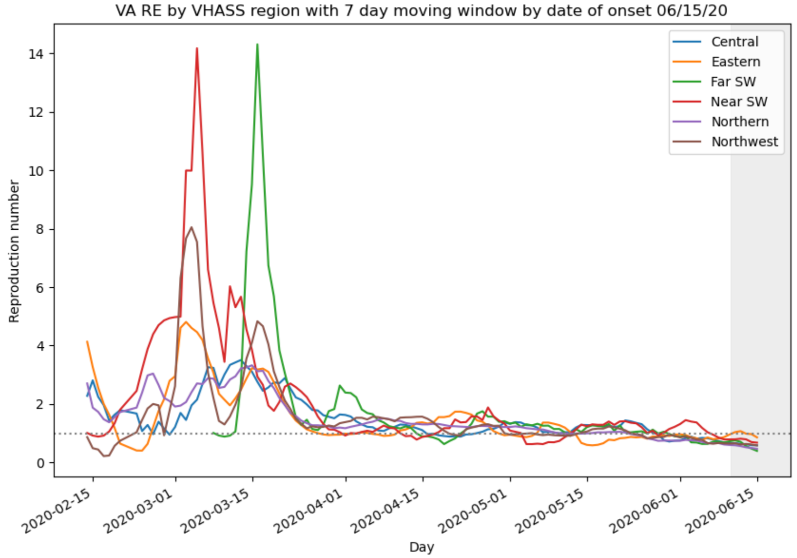
Accessed 10pm June 16, 2020

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



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

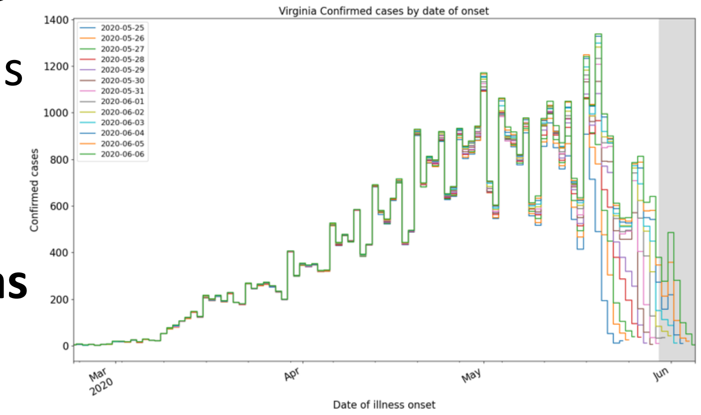
- Wallinga-Teunis method as implemented in EpiEstim[1] R package
- Based on Date of Onset of Symptoms
- Uses serial interval to estimate R_e over time: 6 days (2 day std dev)

Recent Estimates subject to revision as more data comes in

- Date of onset unstable in last 7-14 days

June 6th Estimates

Region	Current R_e	Diff Last Week
State-wide	0.727	0.003
Central	0.828	0.124
Eastern	0.856	0.328
Far SW	0.636	-0.216
Near SW	1.033	-0.088
Northern	0.660	-0.054
Northwest	0.661	-0.283

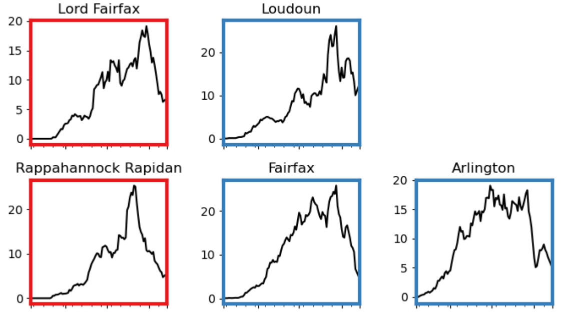


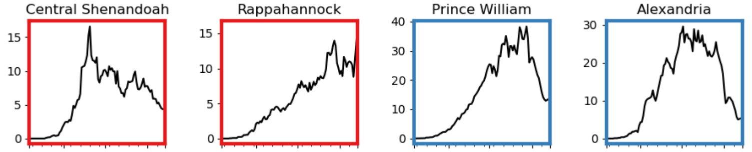
1. Anne Cori, Neil M. Ferguson, Christophe Fraser, Simon Cauchemez. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. American Journal of Epidemiology, Volume 178, Issue 9, 1 November 2013, Pages 1505–1512, https://doi.org/10.1093/aje/kwt133

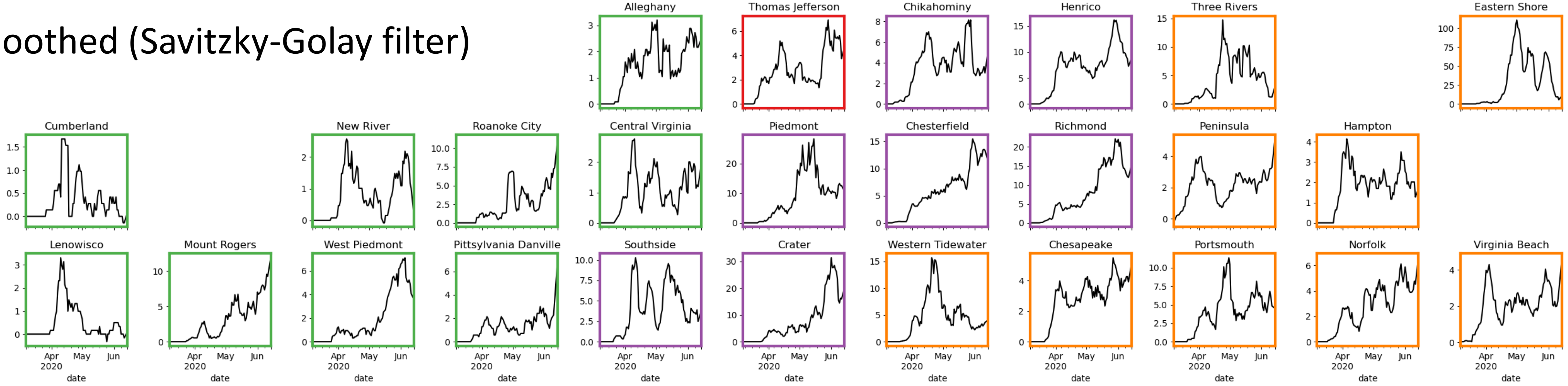
Spatial Adjustments at District Level

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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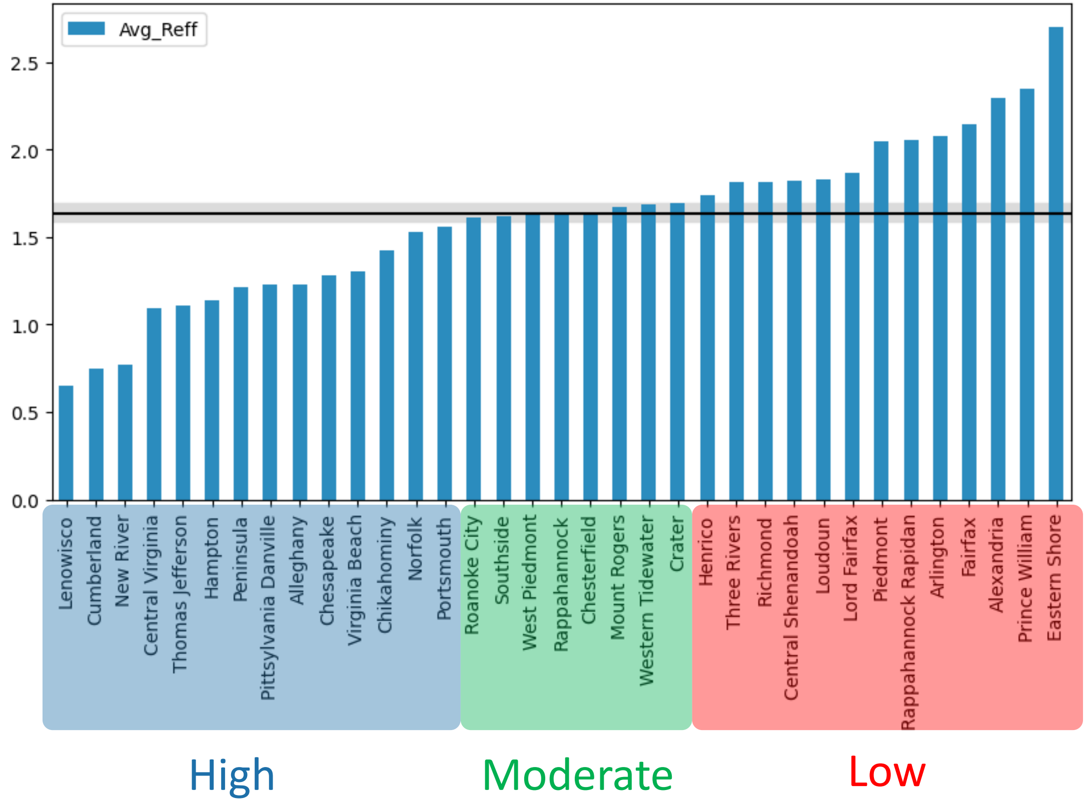
Spatial Adjustments at District Level

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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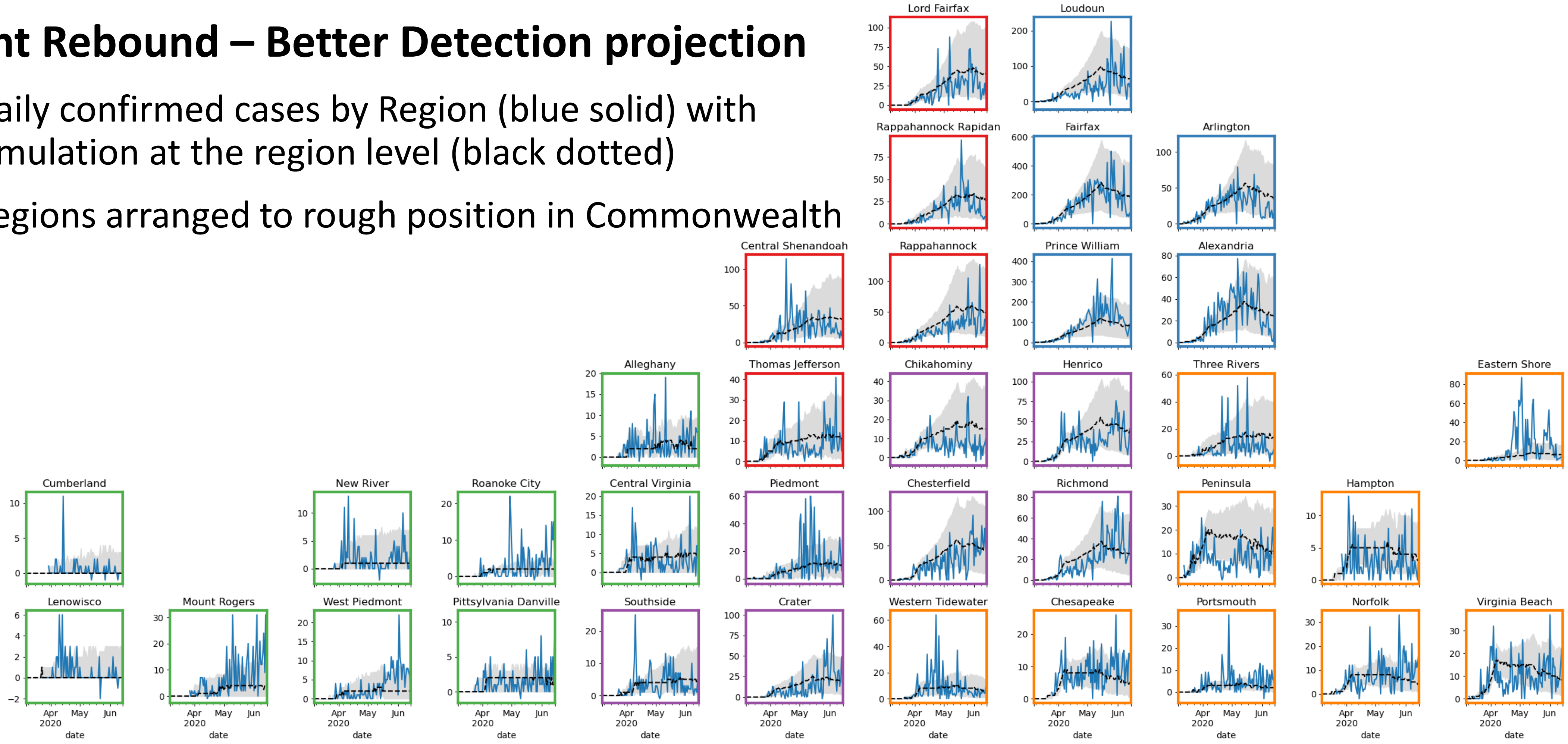
Spatial Adjustments at District Level - Daily

Light Rebound – Better Detection projection

- Daily 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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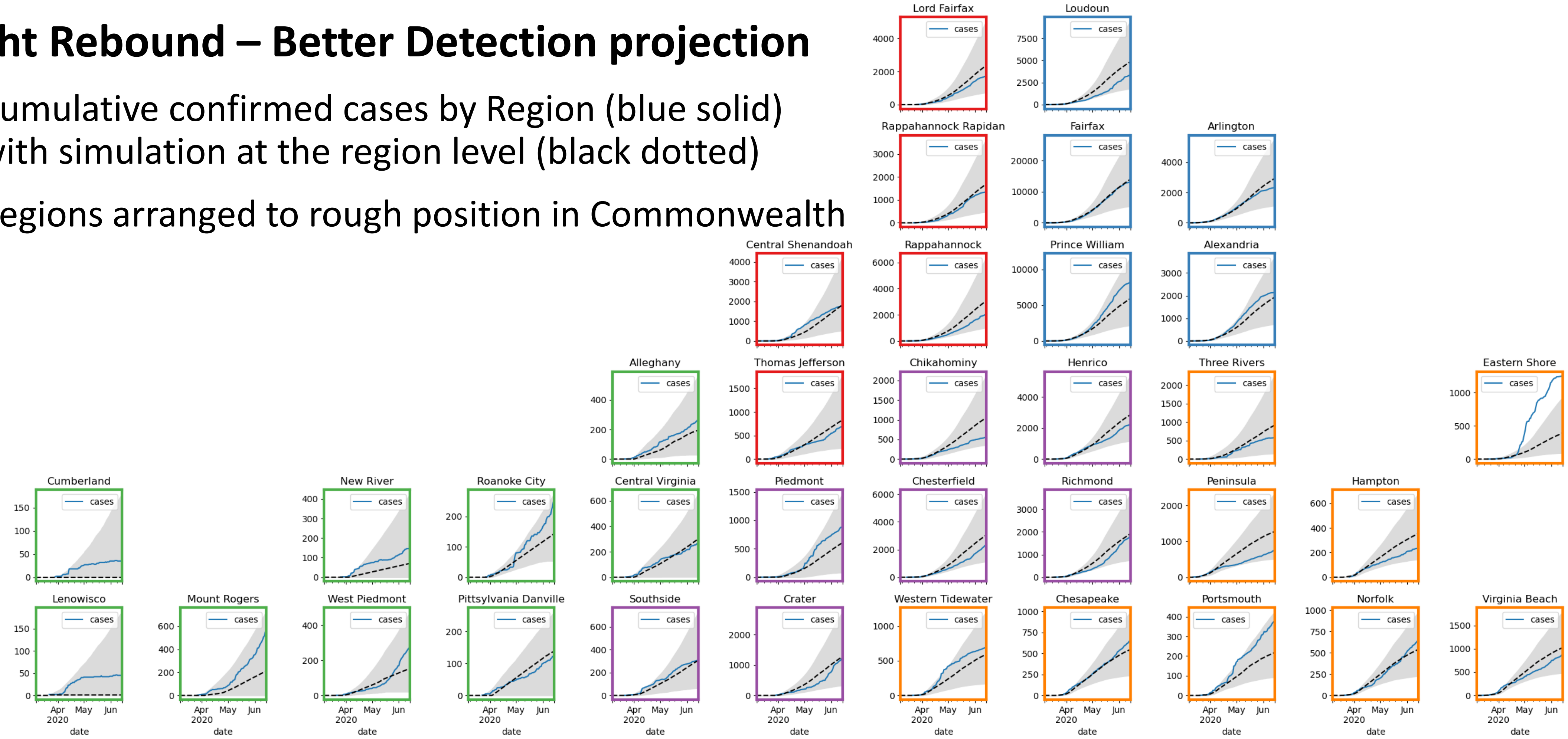
Spatial Adjustments at District Level - Cumulative

Light Rebound – Better Detection 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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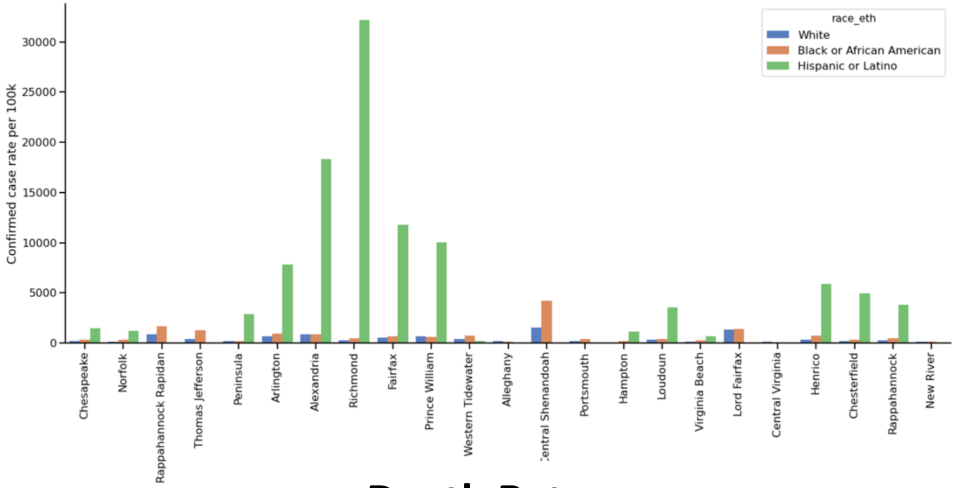
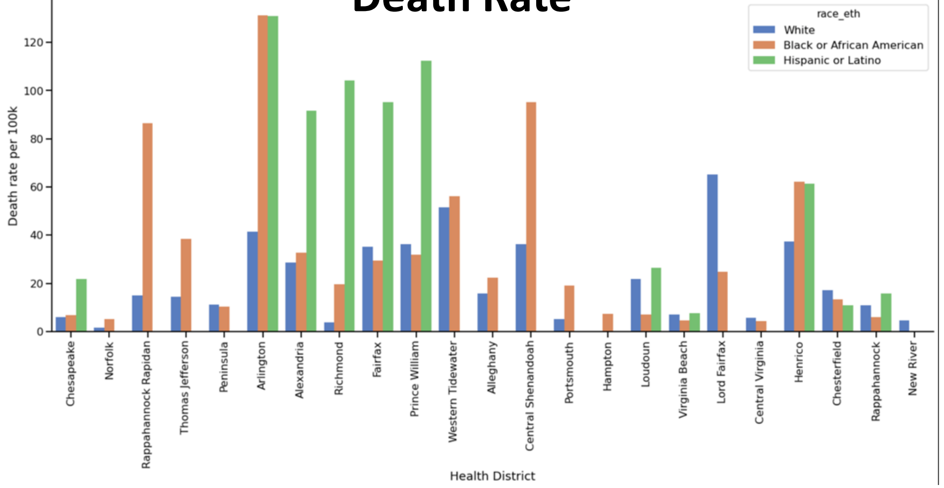
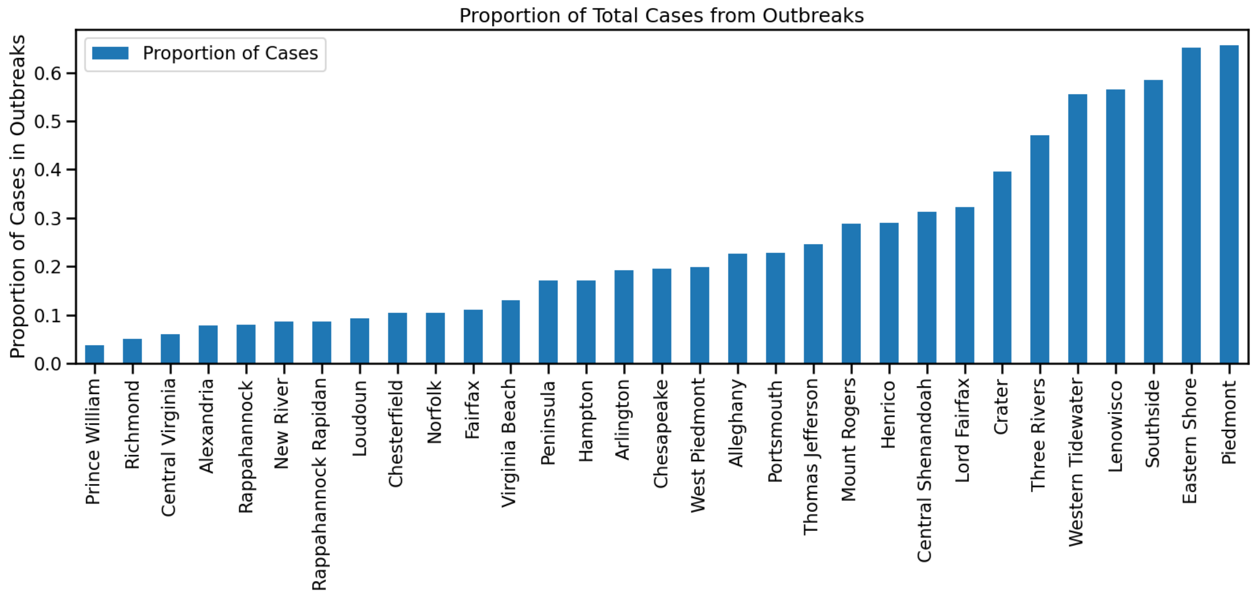
Impact of Race / Ethnicity & Outbreaks

Confirmed Case Rate



Death Rate





Different Races and Ethnicities disproportionally affected

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

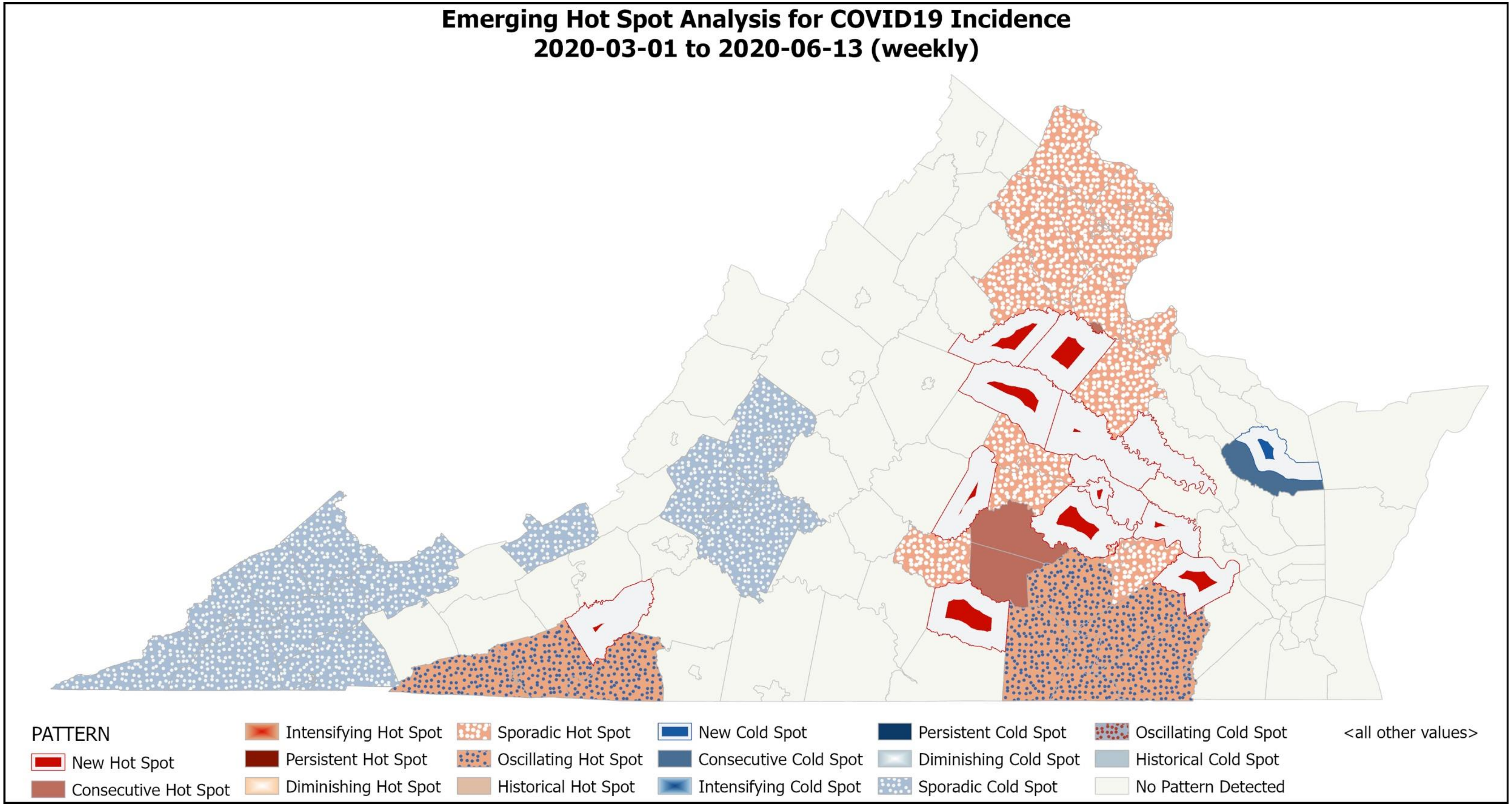
Outbreak Events are hard to predict and affect model fits

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

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



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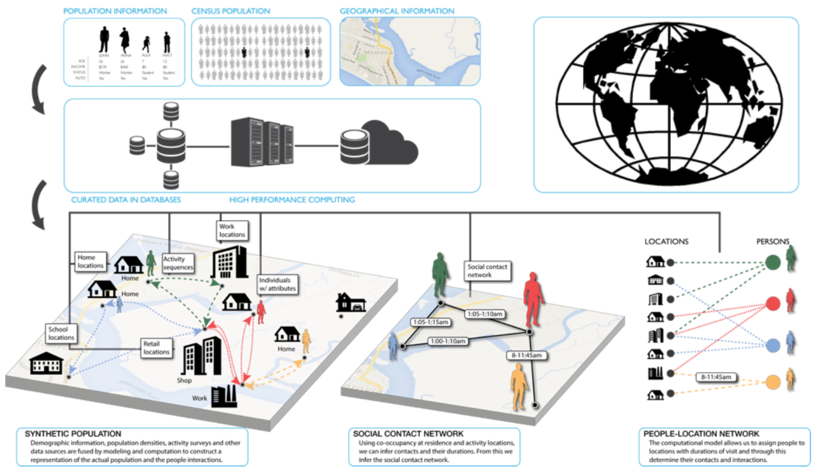
Agent-based Model (ABM)

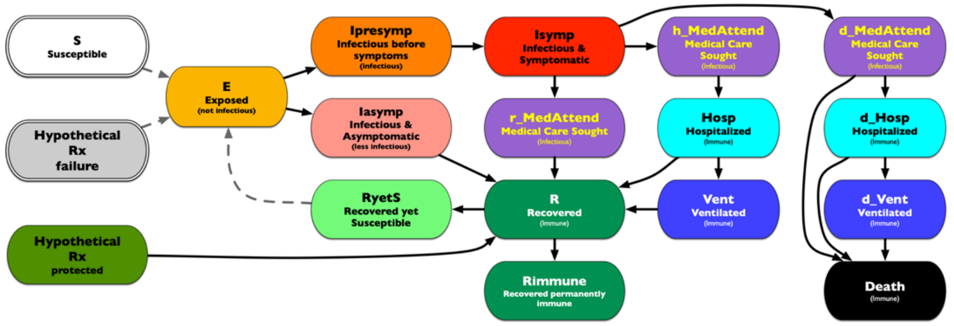
EpiHiper: Distributed network-based stochastic disease transmission simulations

- 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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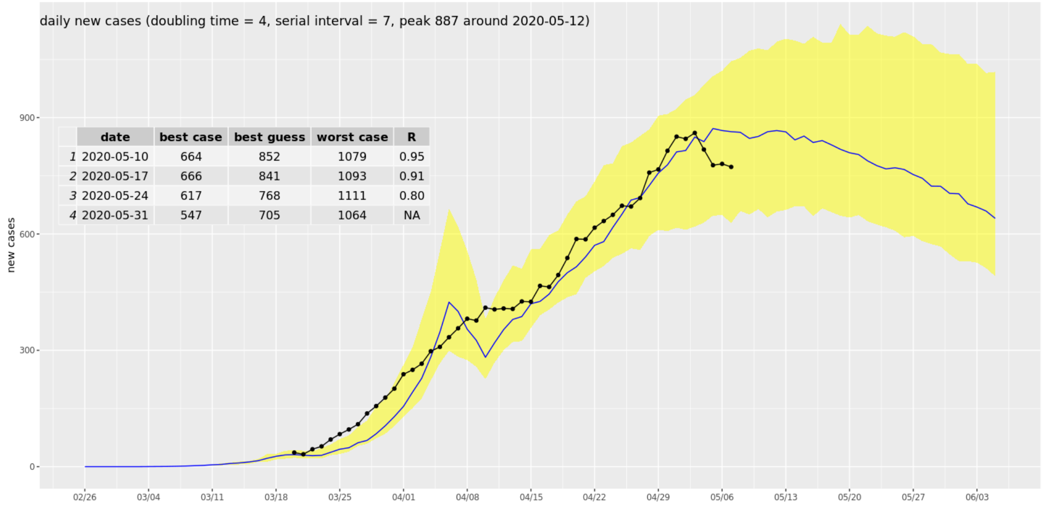
ABM Social Distancing Rebound Study Design

Study of ”Stay Home” policy adherence

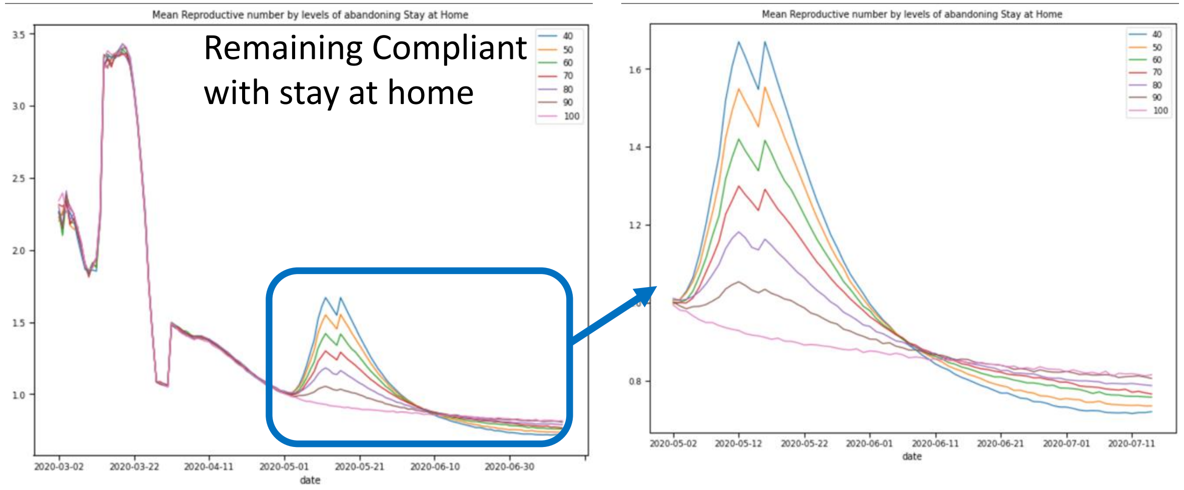
- Calibration to current state in epidemic
- Implement “release” of different proportions of people from ”staying at home”



	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

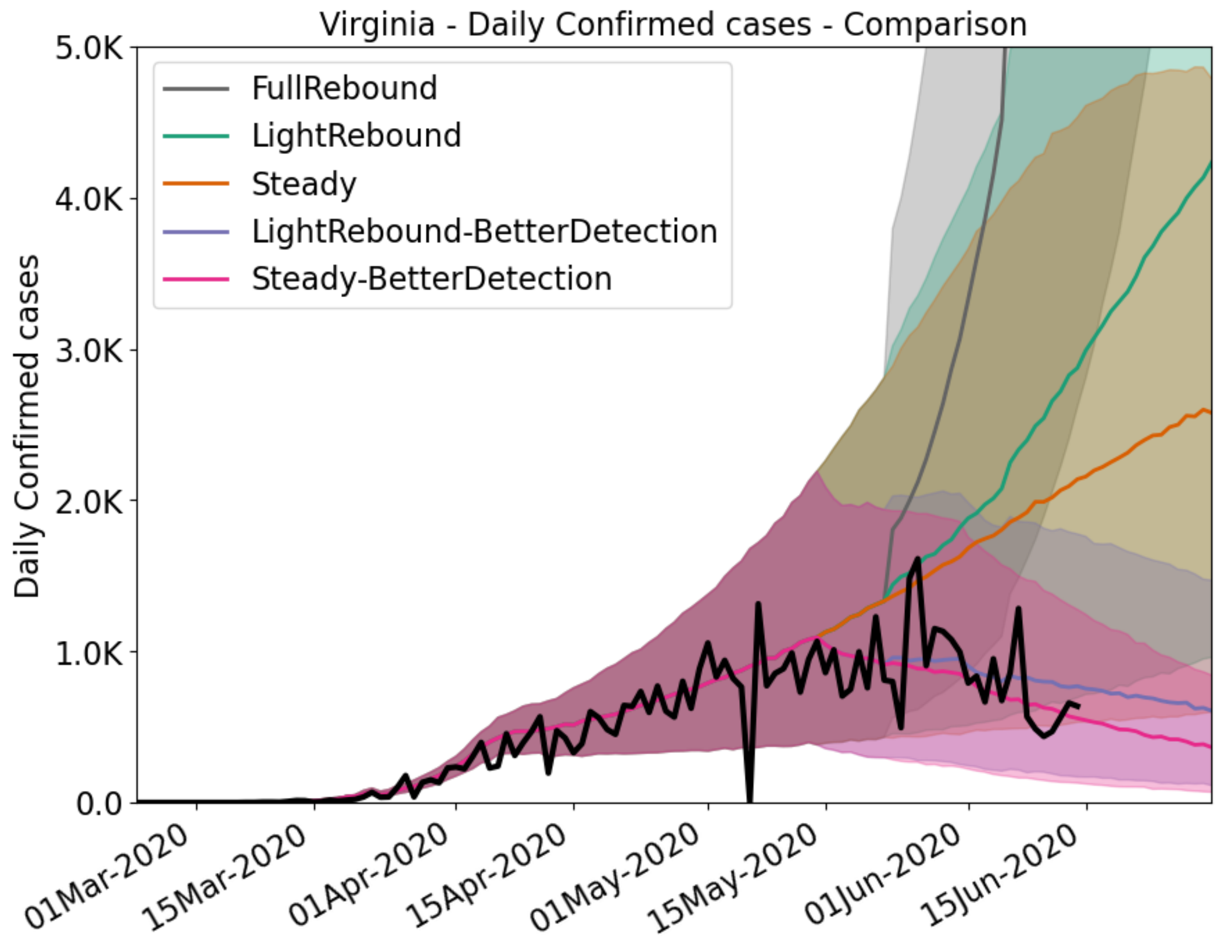


Impacts on Reproductive number with release

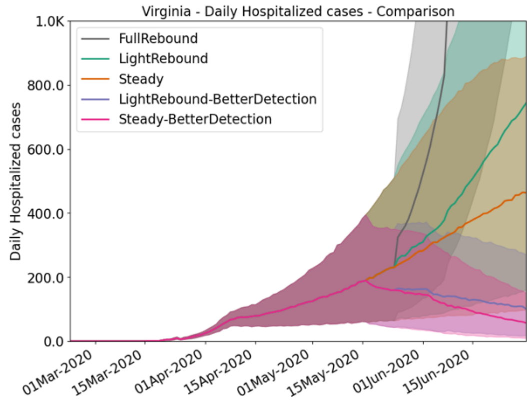
- After release, spike in transmission driven by additional interactions at work, retail, and other
- At 25% release (70-80% remain compliant)
- Translates to 15% increase in transmission, which represents a 1/6th return to pre-pandemic levels

Short-term Projections

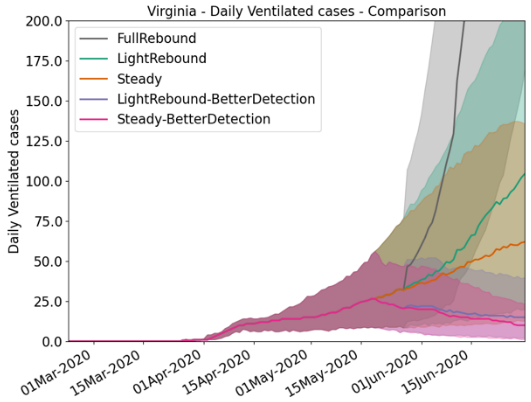
Confirmed cases



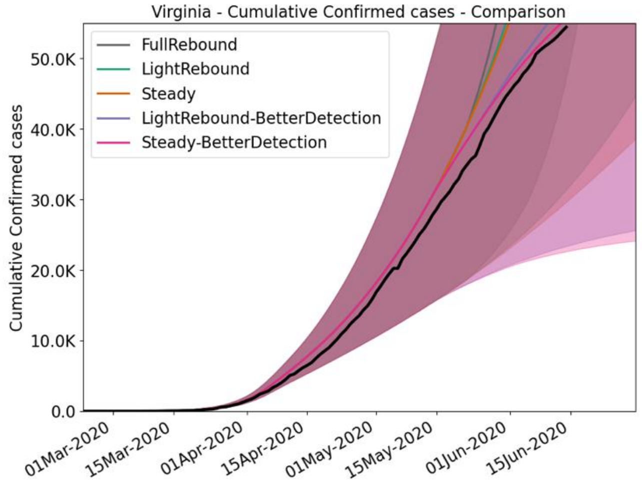
Hospitalizations



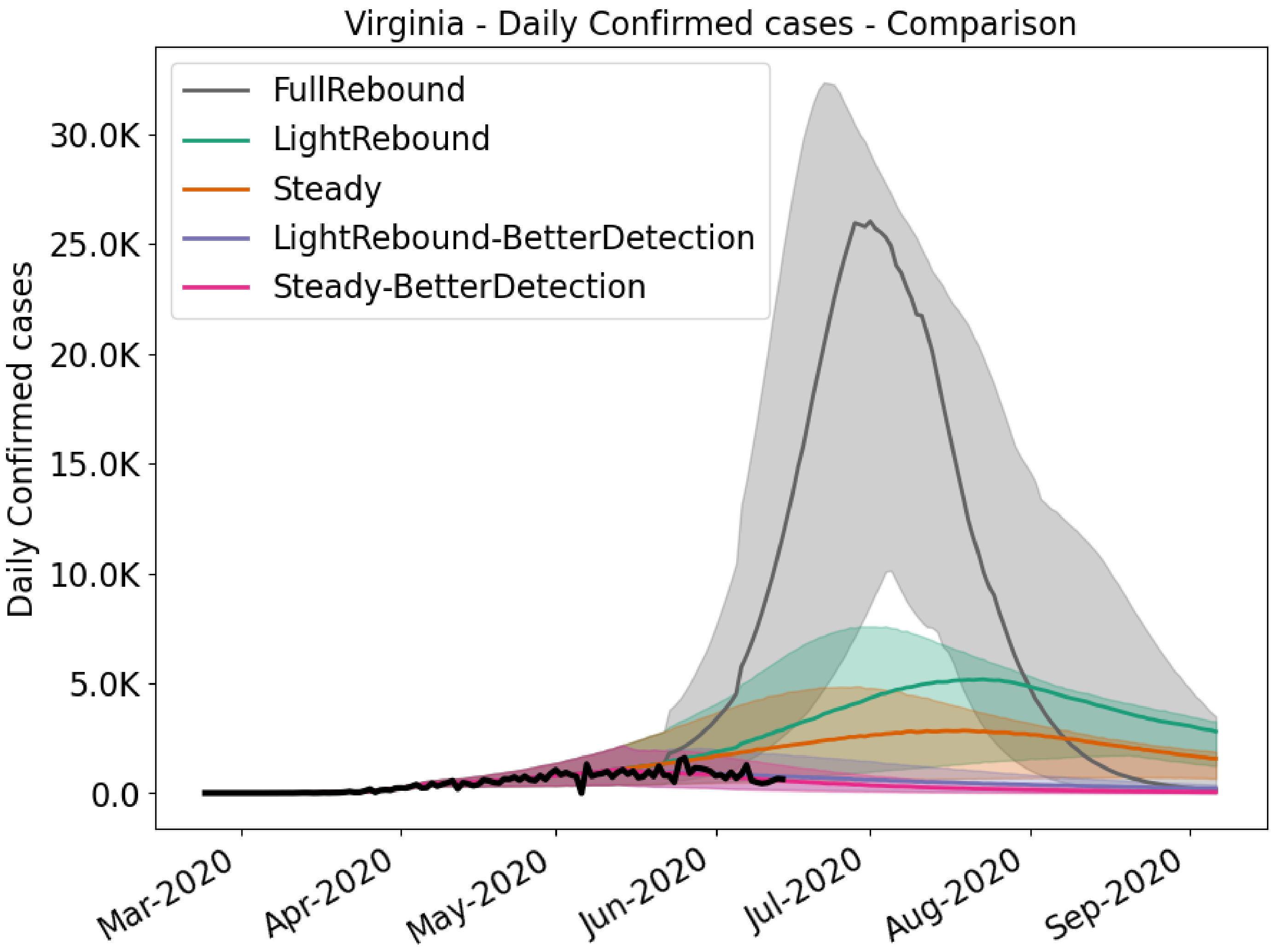
Ventilations



Cumulative Confirmed cases



Period of Transition: Sustaining Control



Weekly New Confirmed Cases*

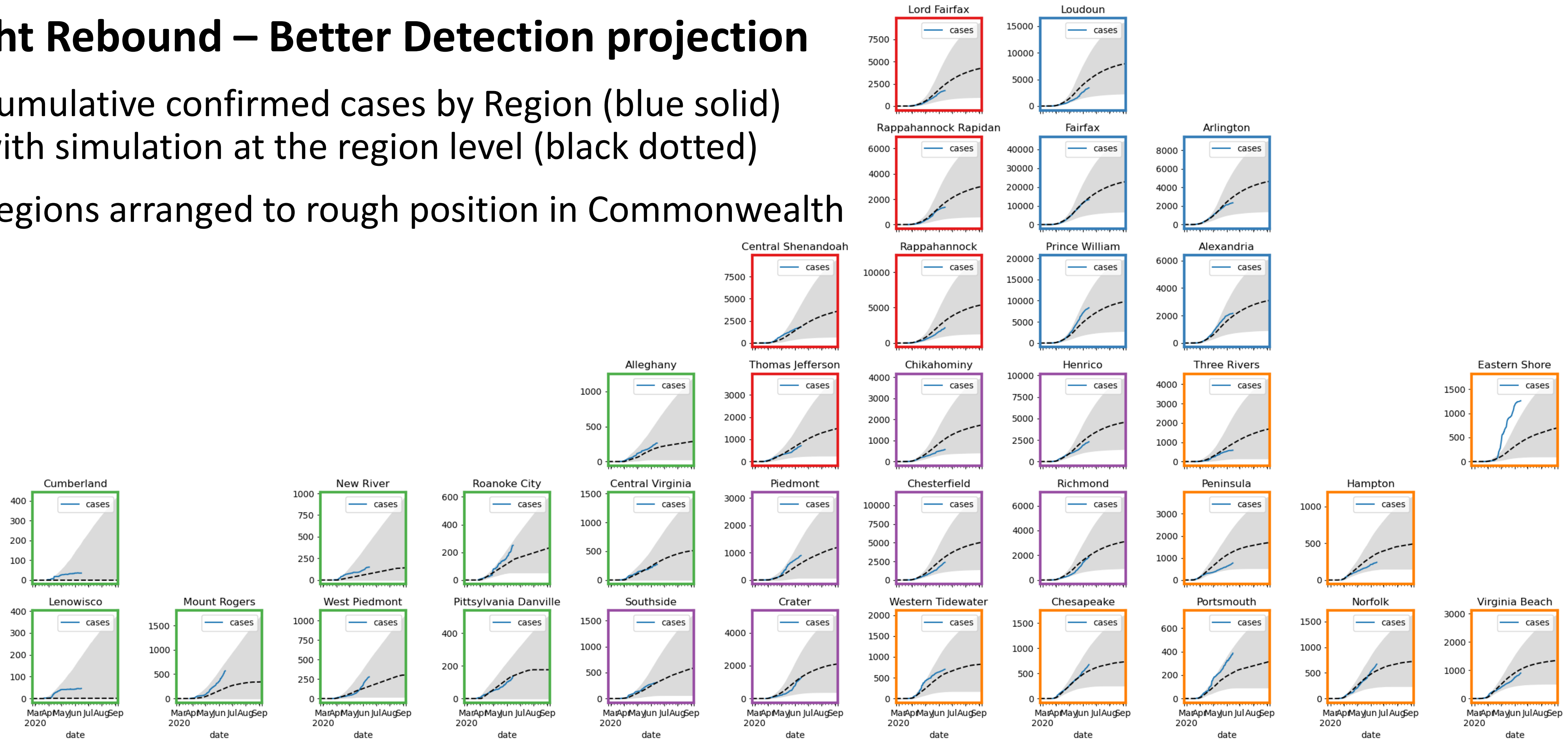
Week Ending	Light Rebound	Steady	Light – Better Detection
6/7/20	13,278	11,900	6,114
6/14/20	17,222	13,604	5,664
6/21/20	21,272	15,308	5,178
6/28/20	25,577	16,889	4,750
7/5/20	29,608	18,152	4,309
7/12/20	33,008	19,110	3,874
7/19/20	34,726	19,565	3,505
7/26/20	34,472	19,306	3,137
8/2/20	32,957	18,450	2,850
8/9/20	30,785	17,274	2,552
8/16/20	28,774	15,878	2,278
8/23/20	26,161	14,444	2,005

*Numbers are medians of projections

District Level Projection - Cumulative

Light Rebound – Better Detection 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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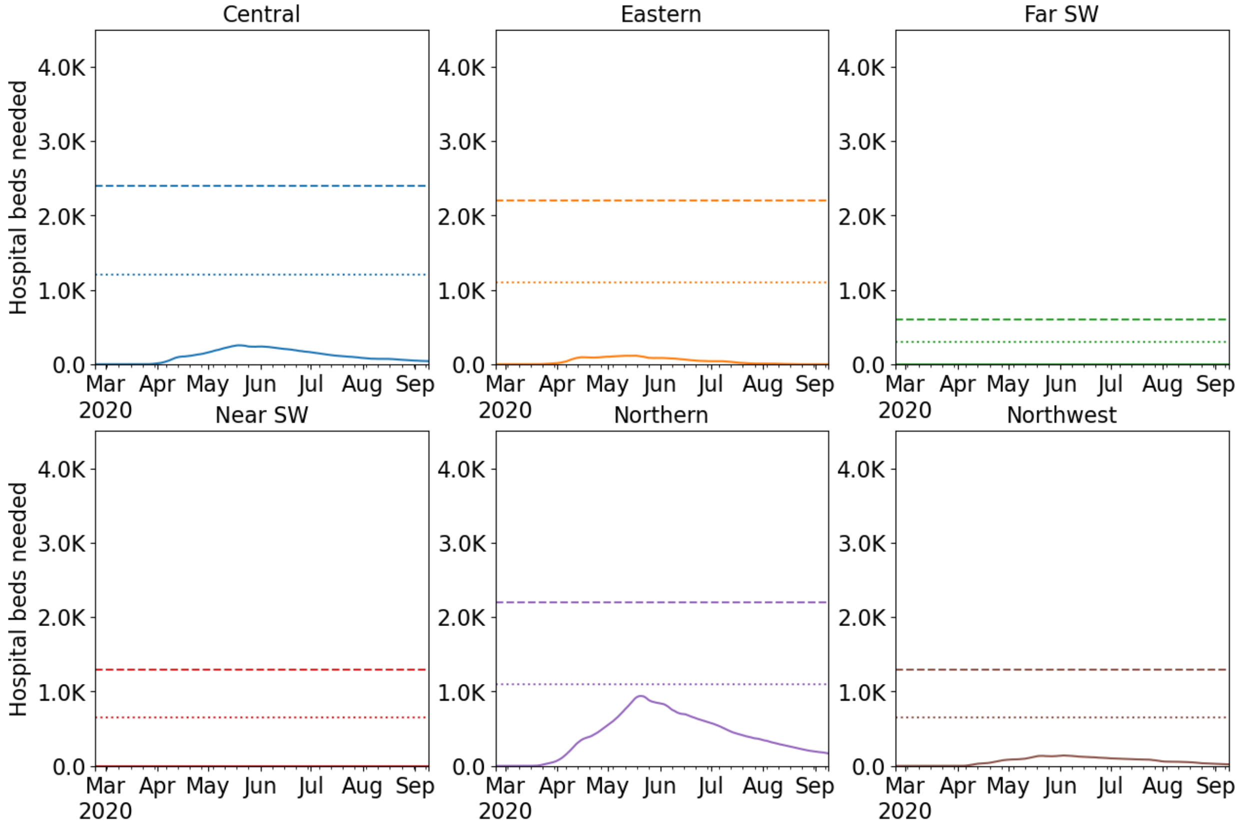
Hospital Demand and Capacity by Region

Capacities by Region – Light Rebound with Better Detection

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 Late Aug
2	Steady	Early July 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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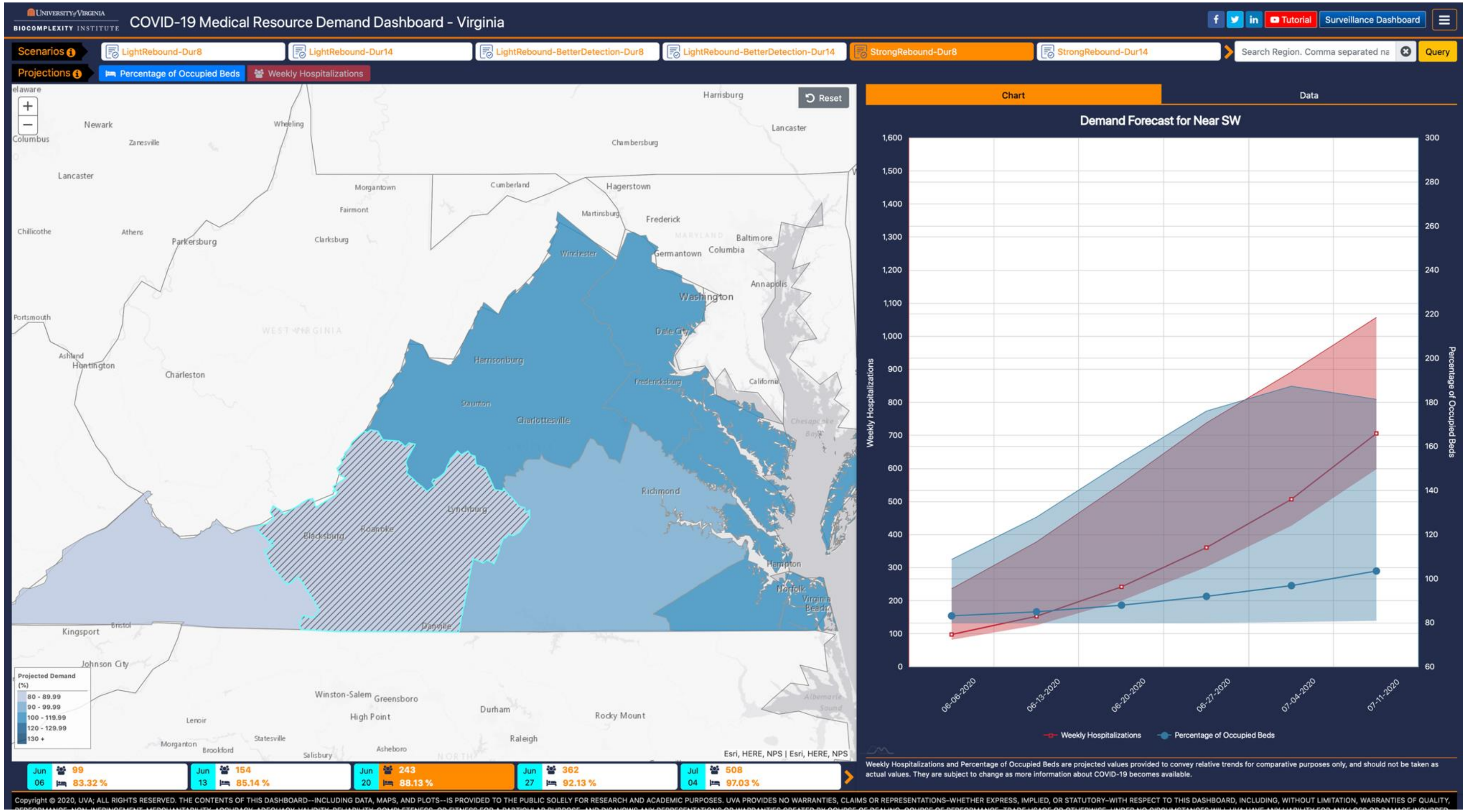
Medical Resource Demand Dashboard

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
  - Better calibrated to district level variations across the Commonwealth
  - Altered projection scenarios to capture increased mixing moderated with good infection practices (decreased risk per interaction)
  - 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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Biocomplexity page for data and other resources related to COVID-19: https://covid19.biocomplexity.virginia.edu/

Questions?

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