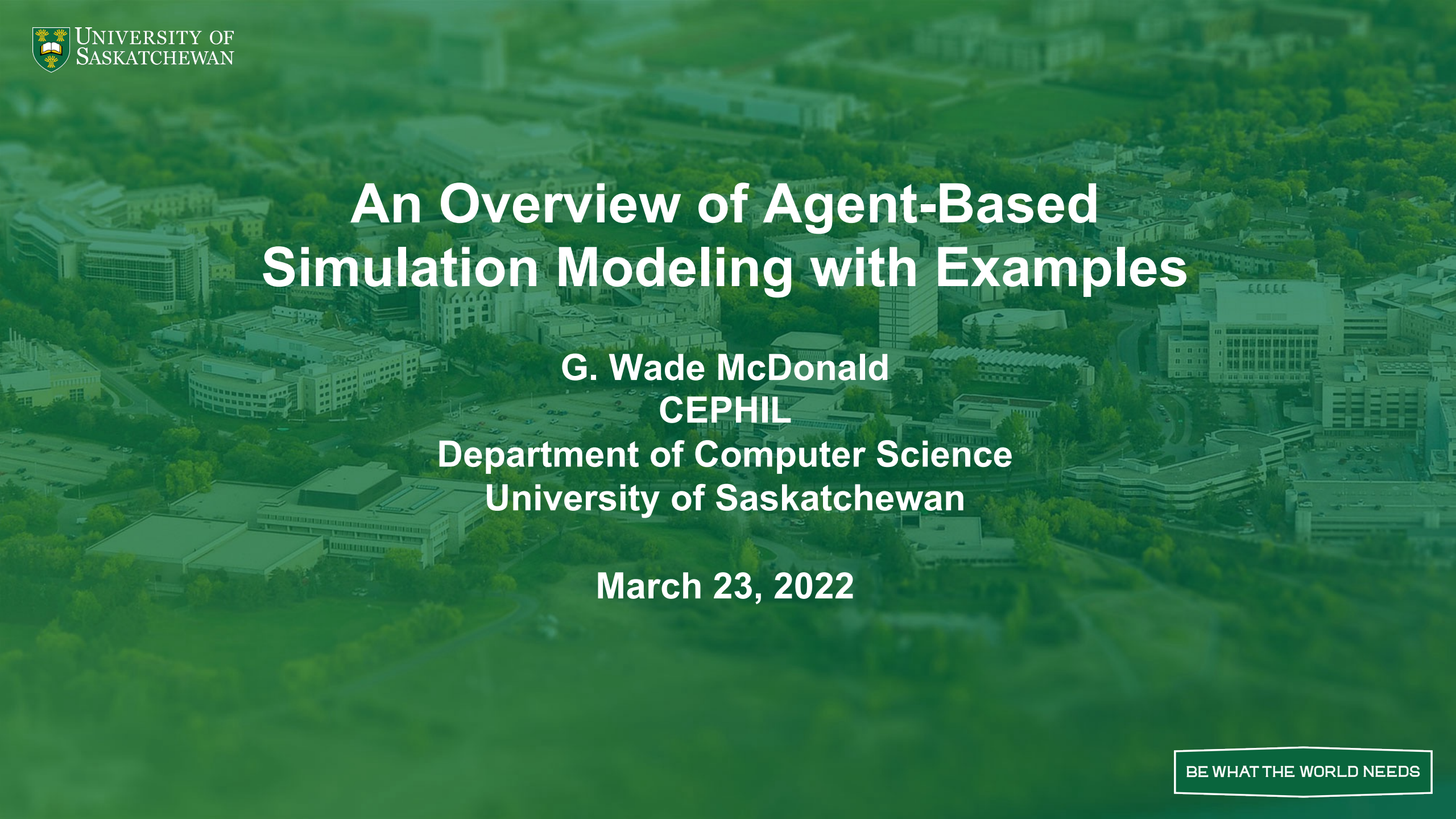

An Overview of Agent-Based Simulation Modeling with Examples

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CEPHIL
Department of Computer Science
University of Saskatchewan

March 23, 2022

Land Acknowledgement

At the University of Saskatchewan, we acknowledge that our main campus sits on Treaty Six Territory and the Homeland of the Métis. We pay our respect to the First Nation and Métis ancestors of this place and reaffirm our relationship with one another.

Outline

- Introduction
- Simulation Modeling
- Pertussis Model
- Chickenpox Model
- COVID-19

Introduction

About Me

- BE in Civil Engineering
- Teaching Experience at the College Level
- BSc in Computer Science
- MSc in Computer Science
- PhD Student in Computer Science
- Working on Epidemiology Problems

CEPHIL

- Computational Epidemiology and Public Health Informatics Lab

- Lead by Dr. Nathaniel D. Osgood, Ph.D.
- In the Department of Computer Science
- At the University of Saskatchewan

- Focussed on applying computer-based simulation models, mobile technologies, and “big” data to understand public health outcomes and policy tradeoffs at a population scale.

Simulation Modeling

What is Simulation Modeling?

- A computer simulation of a complex system.
- Plays out over accelerated time.

- An *approximation* but one that can provide *learning.*

- Compared with Statistical Models:
  - More Detail
  - Greater Computational Burden

Why Build a Simulation Model?

- As A Learning Tool
- Encode a Complex Hypothesis so it can:
  - Be Shared
  - Be Subject to Scrutiny
  - Be Tested
- “What if?” Scenarios

Benefits of a Model Study

- Less expensive that real-world experiments.
- No risk to health or life.
- Fewer ethical issues since real humans are not involved.
- Faster – can test ideas that would play out over years or decades.

Agent-Based Models

Agent Based Models

- Agents are Placed in an Environment
- Agents:
  - Autonomous
  - Unique
  - Local Interaction
- Agents Retain a State that can include History
- Emergent Behaviour is Observed

Agent Based Models

- Advantages:
  - Simple Representation of Heterogeneity
  - Individuality of Agents
  - Local Interaction
- Disadvantages:
  - Compute Intensive, Scaling with Population
  - Less Explainable to Non-Modelers


Spatial Gathering : Simulation - AnyLogic Professional
Camera
x1
Paused

Tools

- AnyLogic (https://www.anylogic.com)
- Repast (https://repast.github.io)
- NetLogo (https://ccl.northwestern.edu/netlogo/)
- Many Others (https://en.wikipedia.org/wiki/Comparison_of_agent-based_modeling_software)

Chickenpox Model

Team

- Principal Investigators:
  - Dr. Alexander Doroshenko
  - Dr. Marwa Farag
  - Dr. Nathaniel Osgood
- Students:
  - Ellen Rafferty
  - Wade McDonald
  - Winchell Qian

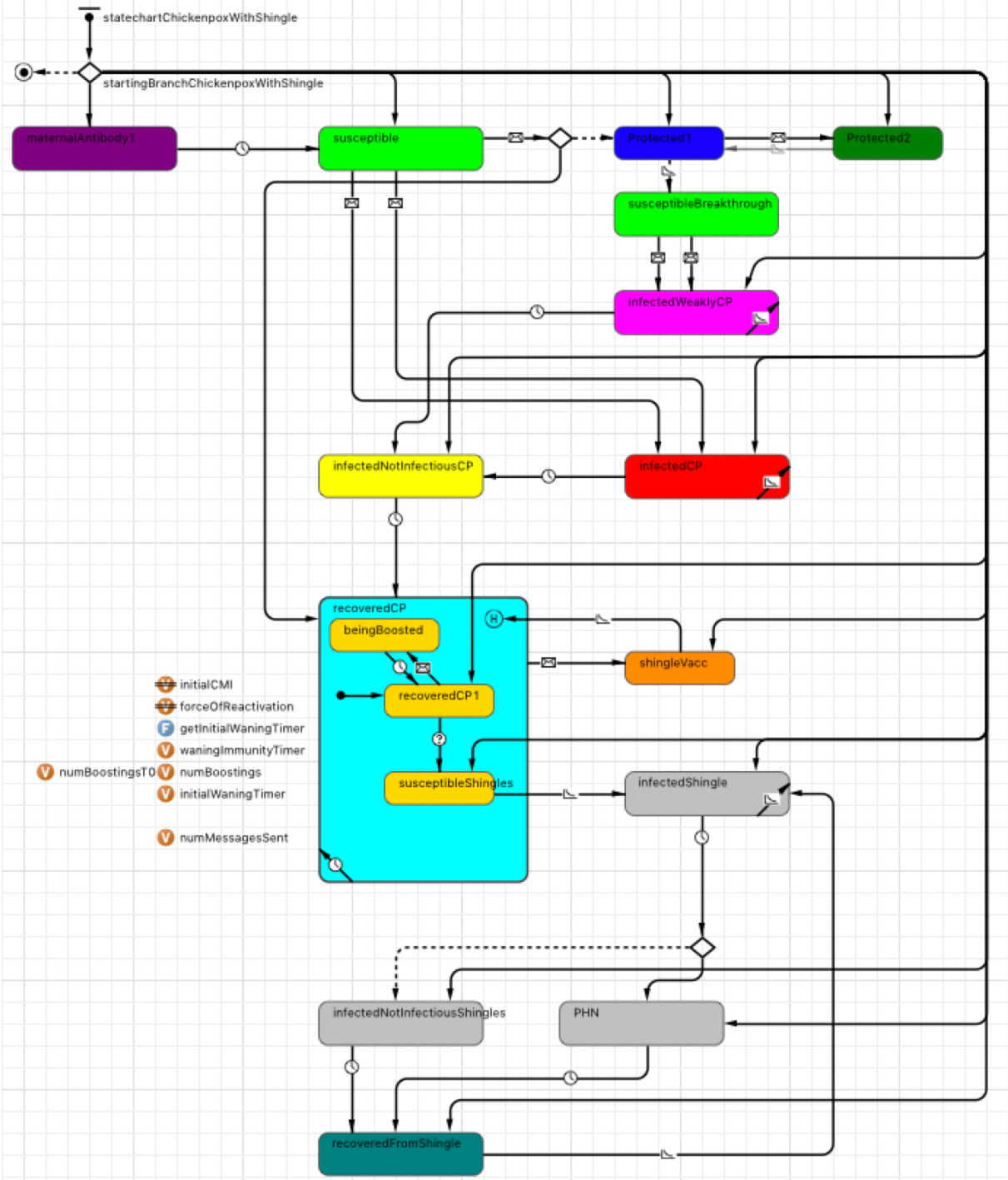
Chickenpox and Shingles

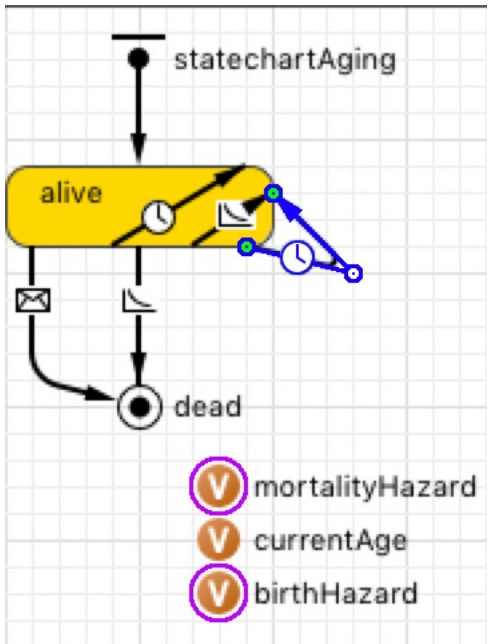
- Both caused by the Varicella Zoster Virus (VZV)
- Chickenpox is a childhood disease
- Virus remains dormant in the body
- Can reactivate later in life as Shingles

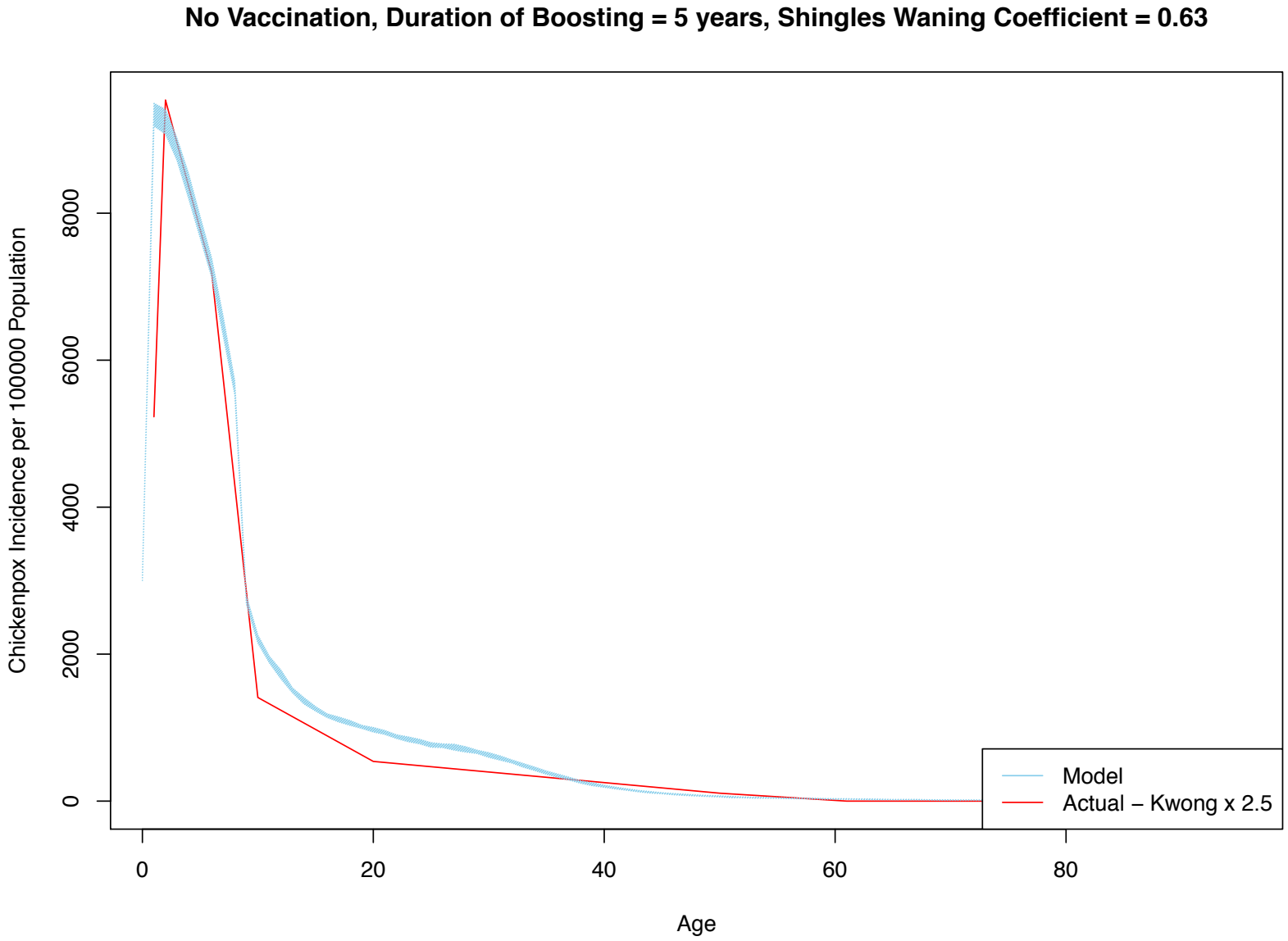
- Does vaccination for Chickenpox cause increased Shingles incidence?

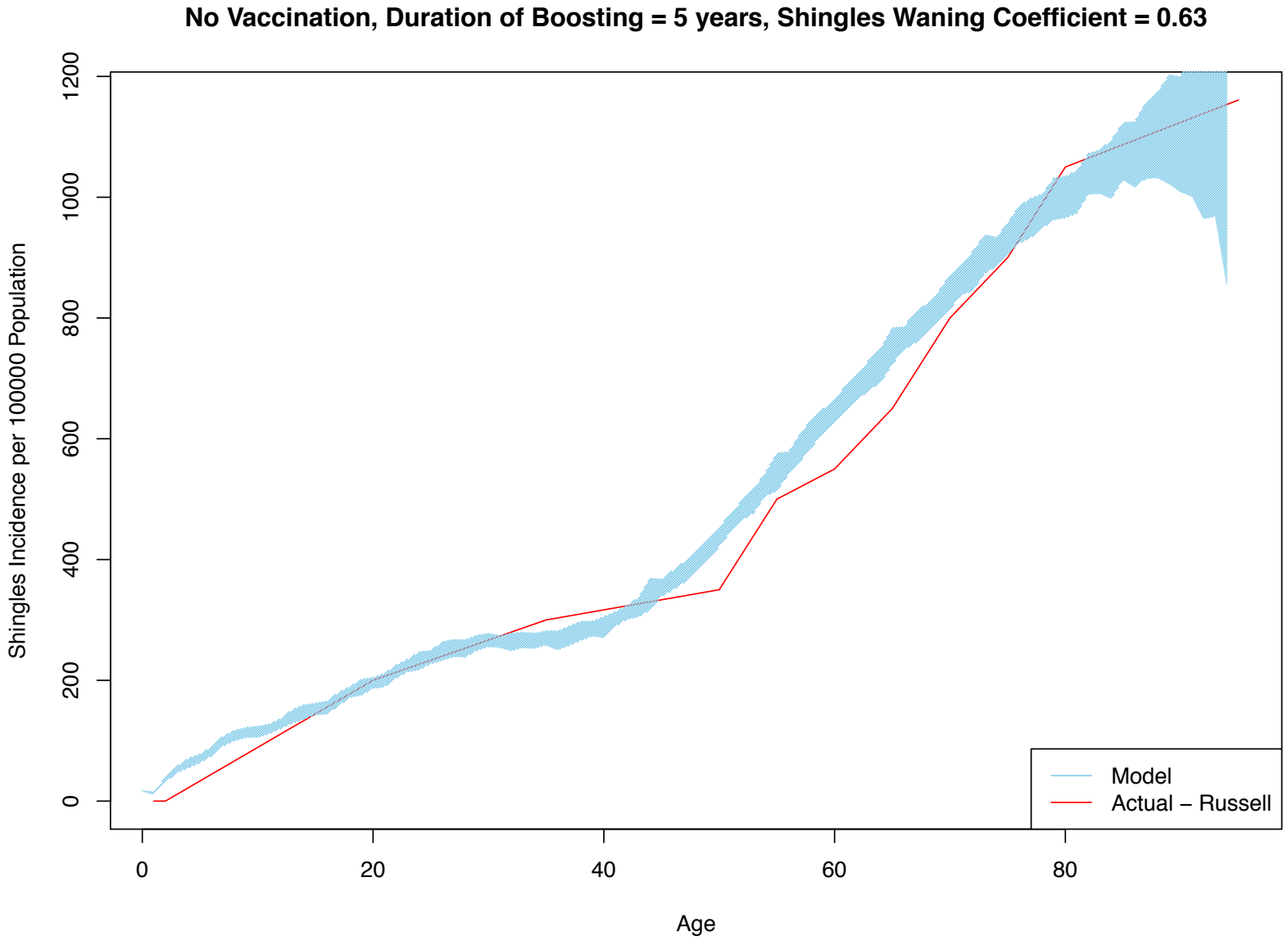
Key Model Features

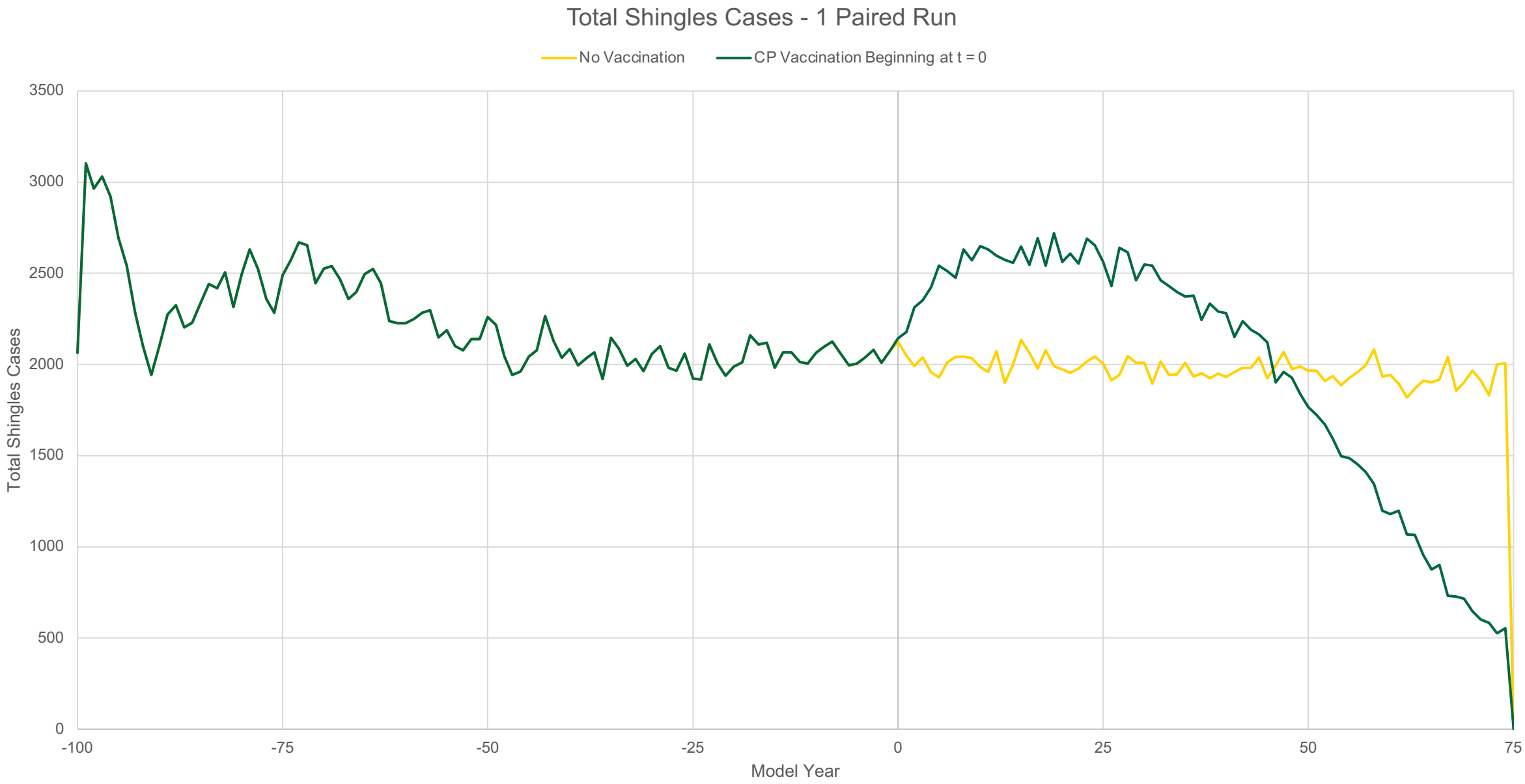
- User-Defined Network of 500,000 Agents
- Open Population
- Preferential Contact Age
- Different Connection Range for each Disease
- Bimodal Population Density

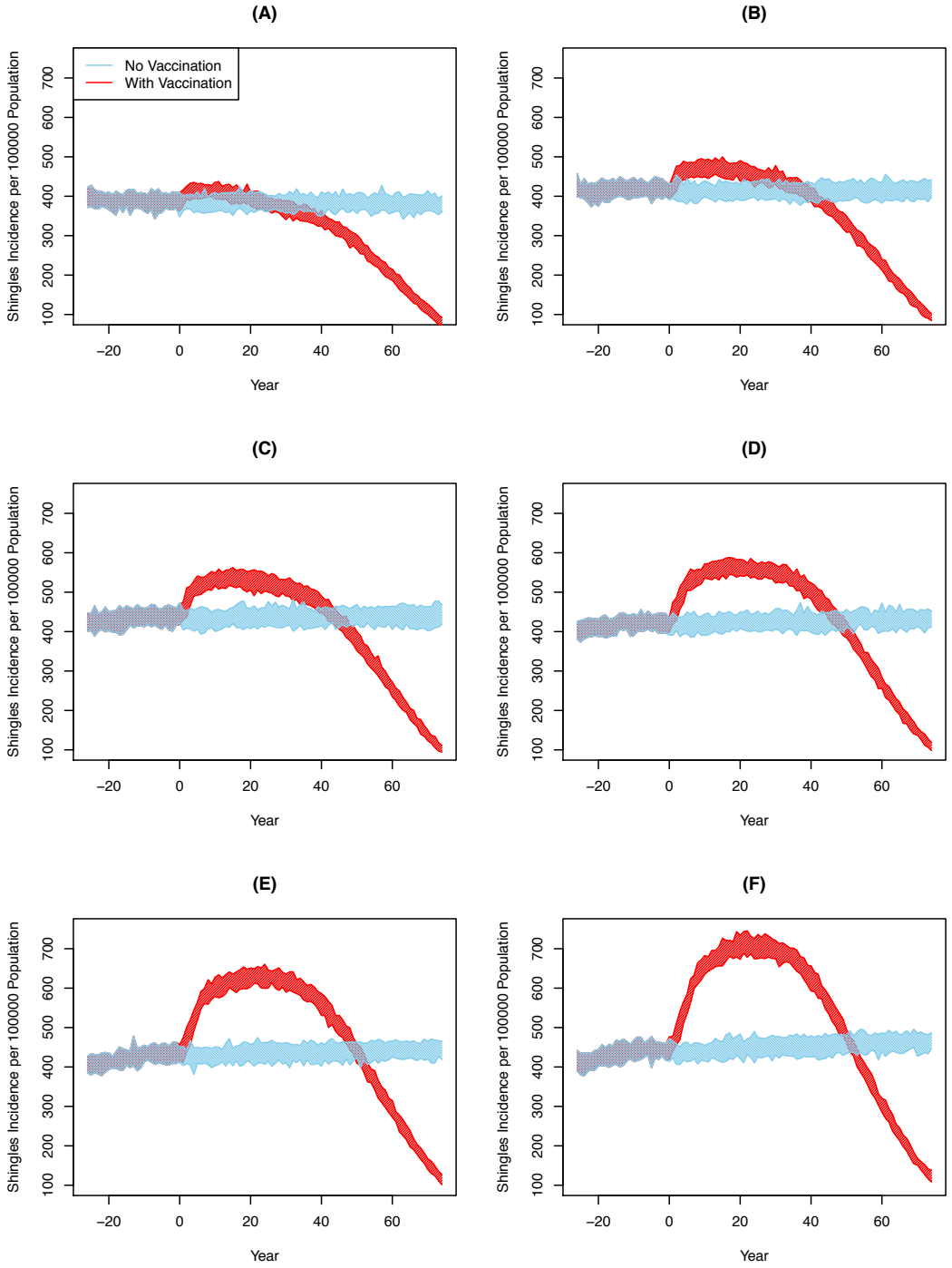



statechartAging
alive
dead
mortalityHazard
currentAge
birthHazard


No Vaccination, Duration of Boosting = 5 years, Shingles Waning Coefficient = 0.63
Chickenpox Incidence per 100000 Population
0
2000
4000
6000
8000
0
20
40
60
80
Age
Model
Actual – Kwong x 2.5


No Vaccination, Duration of Boosting = 5 years, Shingles Waning Coefficient = 0.63
Shingles Incidence per 100000 Population
0
200
400
600
800
1000
1200
0
20
40
60
80
Age
Model
Actual – Russell


Total Shingles Cases - 1 Paired Run
No Vaccination
CP Vaccination Beginning at t = 0
Total Shingles Cases
3500
3000
2500
2000
1500
1000
500
0
-100
-75
-50
-25
0
25
50
75
Model Year


(A)
(B)
(C)
(D)
(E)
(F)
No Vaccination
With Vaccination
Shingles Incidence per 100000 Population
100
200
300
400
500
600
700
−20
0
20
40
60
Year

What good did the model do?

- Has been used to test questions on:
  - Effect of Chickenpox Vaccination on Shingles
  - Optimum Vaccination Schedule for Chickenpox
  - Cost Effectiveness of Chickenpox Vaccination

Pertussis Model

Group Model Building

- Group Model Building
- Team:
  - Principal Investigators:
    - Dr. Alexander Doroshenko, MD, MPH
    - Dr. Nathaniel Osgood, PhD
  - Model Builders:
    - Dr. Karsten Hempel, PhD
    - Mr. Wade McDonald, BE, BSc

Advisory Panel

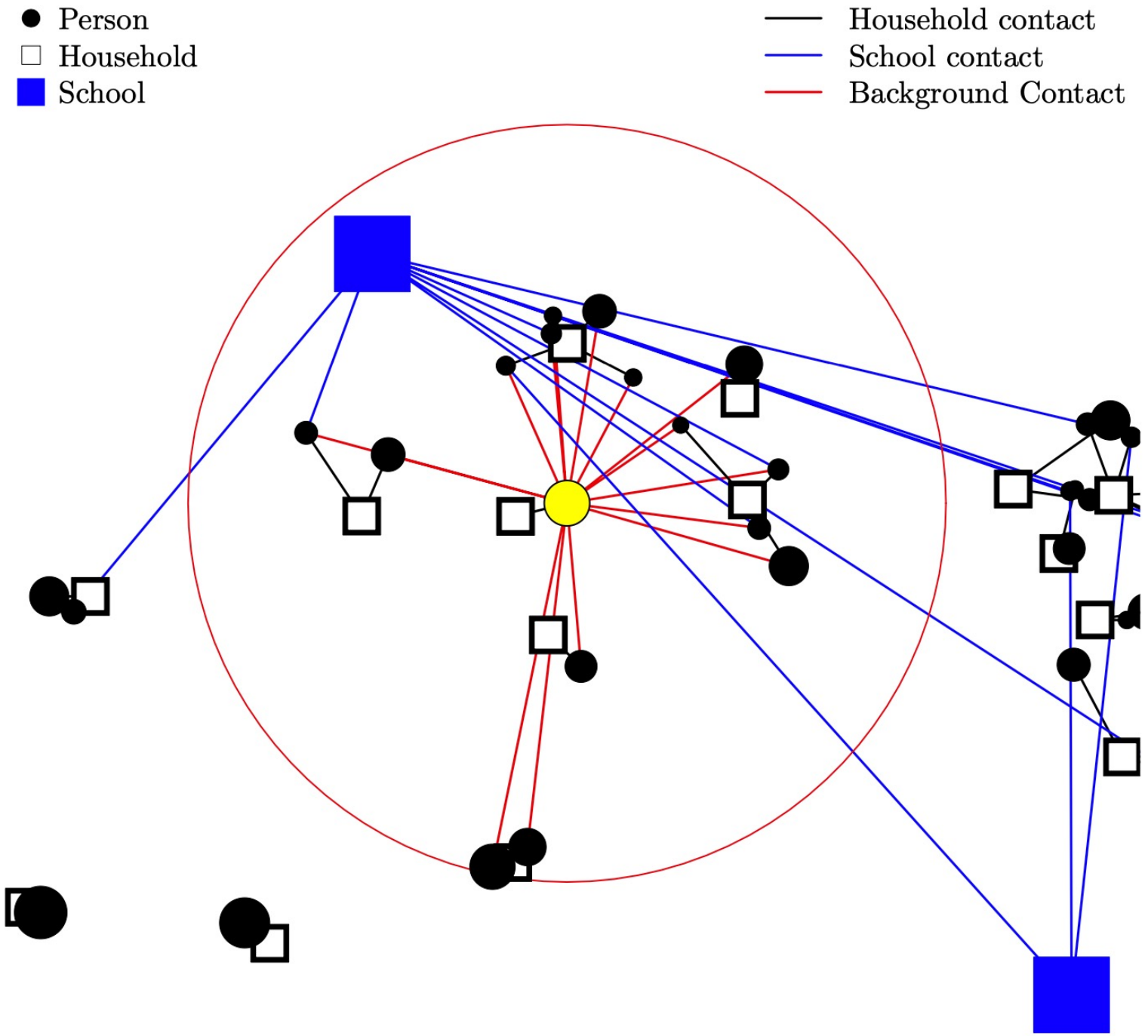
- Advisory Panel:
  - Dr. Natasha Crowcroft, MD, PhD
  - Dr. David Fisman, MD, MPH
  - Dr. Scott Halperin, MD
  - Dr. Nicola Klein, MD, PhD
  - Dr. Pejman Rohani, PhD

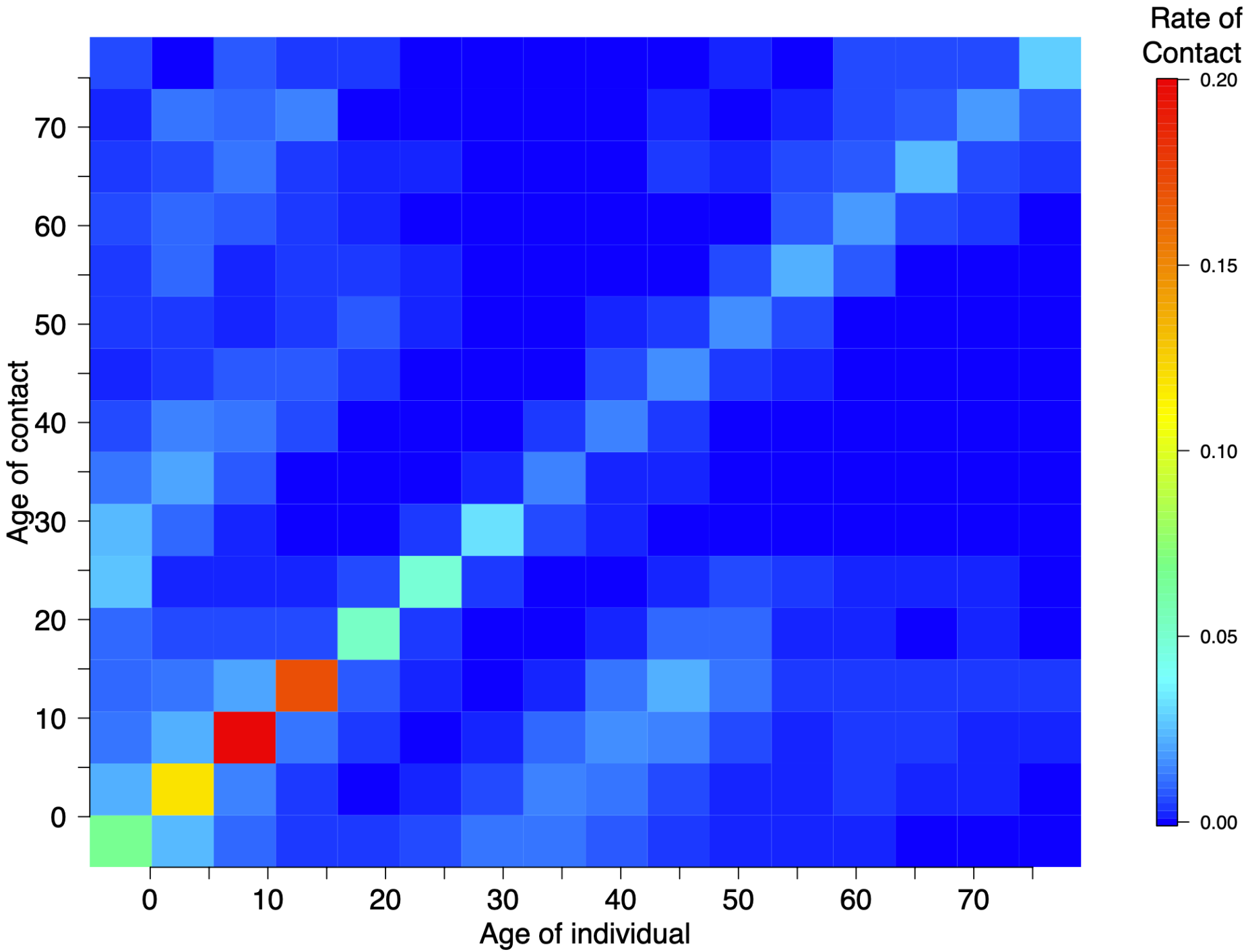
Modeling Process

- Envisioned as an extension of Doroshenko et al. (2016)
- Primary Model Builders worked independently
- Coordinated with weekly video meetings
- Met with local co-PI to discuss progress and issues
- Occasional 3-4 day intensive work sessions
- Approximately quarterly meetings with Advisory Panel

Key Model Features

- Tile-based space allowing for varying population density
- Distance-based network
- Schools and Households as Contact Venues
- Data structure to optimize range search
- Continuous representation of immunity state


Person
Household
School
Household contact
School contact
Background Contact


Rate of Contact
0.20
0.15
0.10
0.05
0.00
Age of contact
0
10
20
30
40
50
60
70
Age of individual
0
10
20
30
40
50
60
70

Health Research Question

- Can immunization of expectant mothers in the third trimester of pregnancy reduce incidence of pertussis in infants?

Outcomes

- Given model assumptions, immunization during pregnancy can reduce pertussis incidence significantly in the 0-2 month age group.

Should we do it, then?

- Maybe

- Clinical trials will still be necessary to prove safety.
- Vaccination during pregnancy may be a tough sell to expectant mothers.
- Will health care system cover costs?

- This appears to be **a** viable strategy but is it the **best**?

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COVID-19?

BE WHAT THE WORLD NEEDS

What did CEPHIL do?

- Worked with Saskatchewan Health Authority
- Multiple Simulation Models

- Attempted to Anticipate Spread and Health Care Needs
- Examined “what-if” Scenarios for Mitigation

Takeaway

- Science Communication is Very Important

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Want to Learn More?

BE WHAT THE WORLD NEEDS

Bootcamps

- Agent Based & Hybrid Modeling Bootcamp & Incubator for Health & Health Care
  - Conceptualization, Formulation, Implementation for Insight
  - Date: August 22-27, 2022
  - Location: In-Person (Saskatoon) or Remote
  - Contact: osgood@cs.usask.ca

Bootcamps

- Bootcamp on Systems-Data Science
  - Practical Combining Data Science and Systems Science for Health
  - Date: June 27-30, 2022
  - Location: In-Person (Saskatoon) or Remote
  - Contact: osgood@cs.usask.ca

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Thank you!

https://www.cs.usask.ca/research/research-labs/computational-epidemiology-and-public-health-informatics-laboratory.php

BE WHAT THE WORLD NEEDS

Publications

1. Rafferty, Ellen RS, **Wade McDonald**, Nathaniel D. Osgood, Alexander Doroshenko, and Marwa Farag. “What we know now: an economic evaluation of chickenpox vaccination and dose timing using an agent-based model.” *Value in Health* 24, no. 1 (2021): 50-60. https://doi.org/10.1016/j.jval.2020.10.004
2. McLean, Allen, **Wade McDonald**, and Donna Goodridge. “Simulation Modeling as a Novel and Promising Strategy for Improving Success Rates with Research Funding Applications: A Constructive Thought Experiment.” *JMIR Nursing* 3, no. 1 (2020): e18983. https://nursing.jmir.org/2020/1/e18983
3. Rafferty, Ellen RS, **Wade McDonald**, Nathaniel D. Osgood, Weicheng Qian, and Alexander Doroshenko. “Seeking the Optimal Schedule for Chickenpox Vaccination in Canada: Using an Agent-Based Model to Explore the Impact of Dose Timing, Coverage and Waning of Immunity on Disease Outcomes.” *Vaccine* 38, no. 3 (2020): 521-529. https://doi.org/10.1016/j.vaccine.2019.10.065
4. McLean, Allen, **Wade McDonald**, Donna Goodridge, and Nathaniel Osgood. “Agent-Based Modeling: A Method for Investigating Challenging Research Problems.” *Nursing Research* 68, no. 6 (2019): 473-482. https://doi.org/10.1097/NNR.0000000000000390
5. Rafferty, Ellen, **Wade McDonald**, Weicheng Qian, Nathaniel D. Osgood, and Alexander Doroshenko. “Evaluation of the Effect of Chickenpox Vaccination on Shingles Epidemiology using Agent-Based Modeling.” *PeerJ* 6 (2018): e5012. https://peerj.com/articles/5012/