Challenges and Opportunities for Modeling Dengue and Chikungunya

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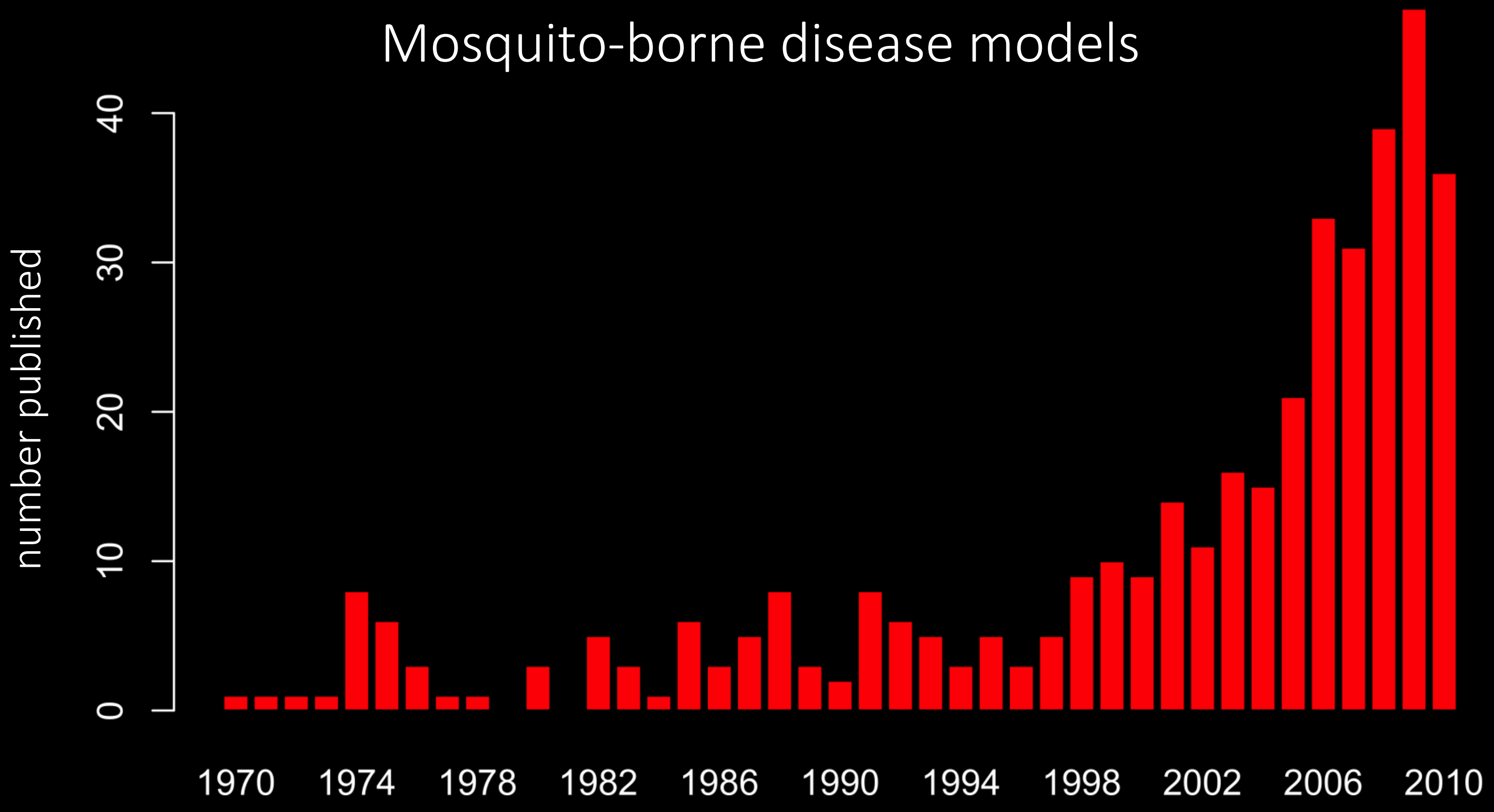
Mosquito-borne disease models



Reiner, Perkins, et al. *J. R. Soc. Interface* 2013

Modeling for decisions:

chikungunya & dengue

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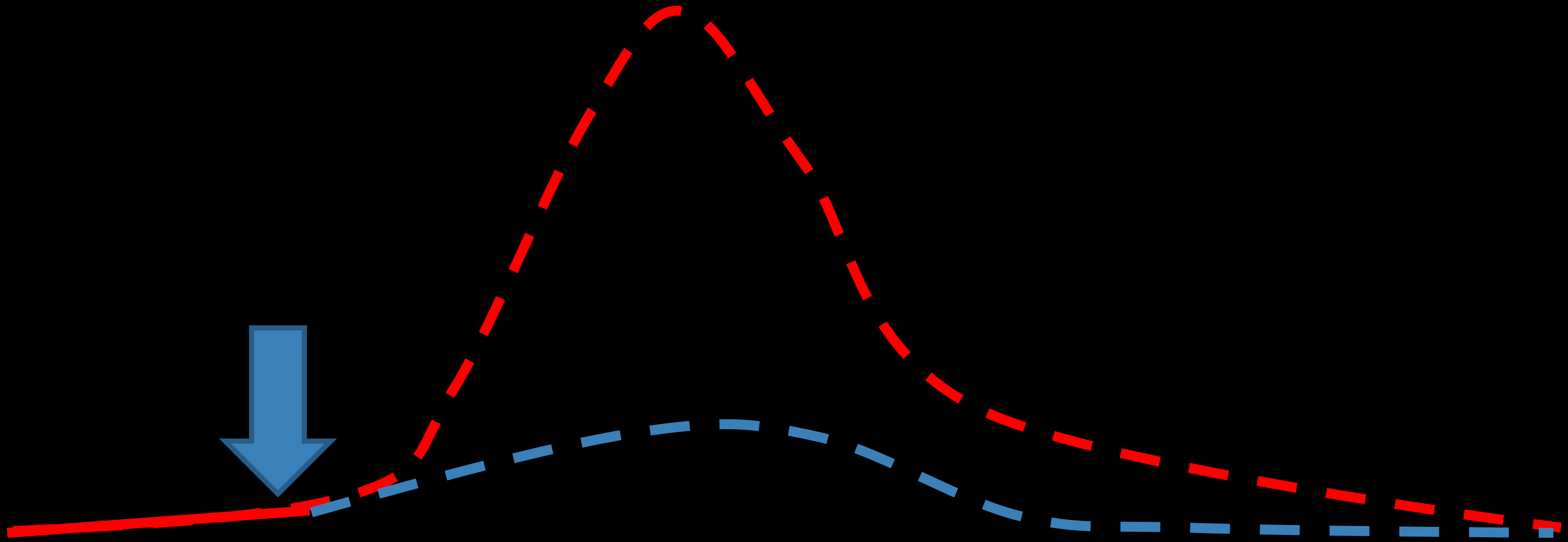
DEPARTMENT OF HEALTH & HUMAN SERVICES · USA

CDC CENTERS FOR DISEASE CONTROL AND PREVENTION

EVERY decision is
based on a model.





EVERY public health decision is based on a model.

EVERY public health decision is based on a model.

Public health decisions CAN be informed by quantitative models.

EVERY public health decision is based on a model.

How?

Public health decisions CAN be informed by quantitative models.

A pathway for informing decisions

1. Establish objectives and targets
2. Identify, acquire, and/or simulate data
3. Formulate models
4. Evaluate predictions


South Carolina
Mississippi
Alabama
Georgia
Bermuda
ouisiana
Florida
Gulf of Mexico
The Bahamas
Turks and Caicos Islands
Cuba
Yucatán
Quintana Roo
Campeche
Cayman Islands
Haiti
Dominican Republic
Puerto Rico
Jamaica
Belize
Guatemala
Honduras
Dominica
Caribbean Sea
St Lucia
El Salvador
Barbados
Nicaragua
Aruba
Curacao
Grenada
Costa Rica
Trinidad and Tobago
Panama
Venezuela

Targets

Key characteristics

- Common language
- Decision-oriented
- Measurable

Targets

What is the probability of an infected traveler arriving and initiating local transmission in ________?

Data

Key characteristics

- Outcome-oriented
- Training & testing
- Future availability
- Public

Data

1. Incidence

    Asymptomatic

    Unreported

Pan American Health Organization
World Health Organization
Regional Office for the Americas

Number of Reported Cases of Chikungunya Fever in the Americas, by Country or Territory 2013-2014 (to week noted)

Cumulative cases

Epidemiological Week / EW 14 2014 (Updated 4 April 2014)

Country/Territory	Week[a]	Suspected Cases[b]		Confirmed Cases[b]		Deaths	Population[d] X 1000
		Number	Incidence rate[c]	Number	Incidence rate[c]		
Latin Caribbean							
Cuba						0	11,266
Dominican Republic						0	10,404
French Guiana (*)	Week 13	0	0	36	14.5	0	249
Guadaloupe (**)	Week 13	2737	587	802	172.1	1	466
Haiti						0	10,317
Martinique	Week 13	11400	2,822	1,284	317.8	2##	404
Puerto Rico			0	0	0.0	0	3,688
Saint Barthelemy	Week 13	432	4,854	135	1,516.9	0	9
Saint Martin (French part) (***)	Week 13	2840	7,957	790	2,213.5	3#	36
Subtotal		*17409*	47	*3,047*	8.3	6	*36,839*
Non-Latin Caribbean							
Anguilla[$]	Week 13		0	33	206.3	0	16
Antigua & Barbuda			0	0	0.0	0	90
Aruba[$]	Week 6		0	1	0.9	0	109
Bahamas			0	0	0.0	0	377
Barbados			0	0	0.0	0	289
Cayman Islands			0	0	0.0	0	54
Curacao			0	0	0.0	0	147
Dominica (****)	Week 13	558	764	81	111.0	0	73
Grenada			0	0	0.0	0	110
Guyana			0	0	0.0	0	800
Jamaica			0	0	0.0	0	2,784
Montserrat			0	0	0.0	0	5
Saint Kitts & Nevis	Week 8		0	1	2.0	0	51
Saint Lucia^	Week 13		0	1	0.6	0	163
Saint Vincent & the Grenadines			0	0	0.0	0	103
Sint Maarten (Dutch part)[=]	Week 12		0	123	307.5	0	40
Suriname			0	0	0.0	0	539
Trinidad & Tobago			0	0	0.0	0	1,341
Turks & Caicos Islands			0	0	0.0	0	48
Virgin Islands (UK)	Week 10		0	7	21.9	0	32
Virgin Islands (US)			0	0	0.0	0	105
Subtotal		*558*	8	*247*	*3.4*	*0*	7,276
TOTAL		17967	41	3,294	7.5	6	44,115

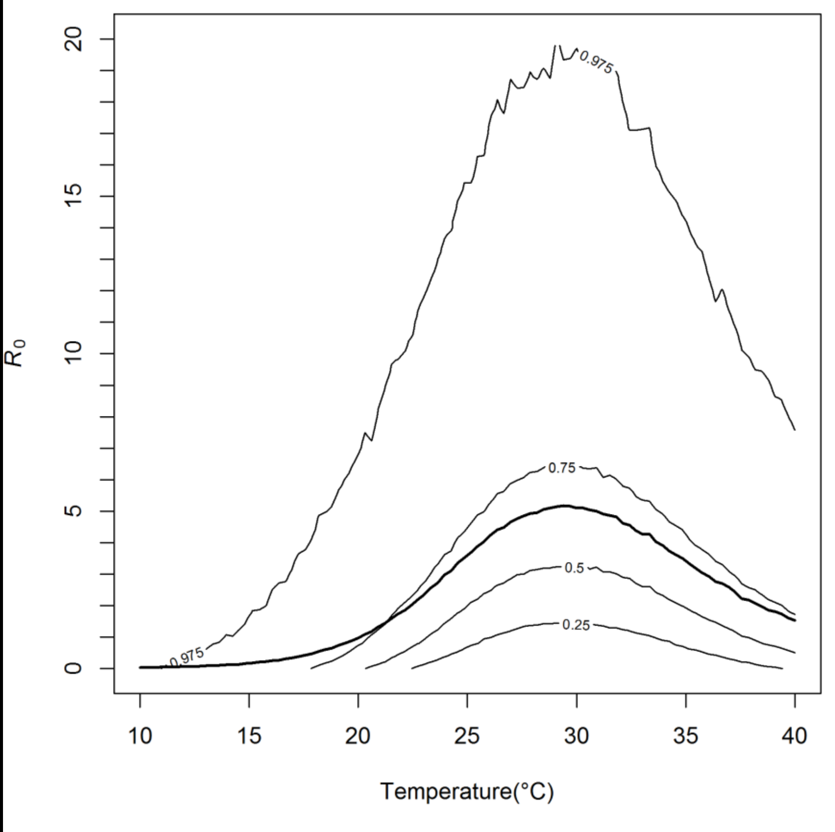
Data

1. Incidence
2. Movement

    Long-term change
    Differences for cases
    Response to epidemic

Data

1. Incidence
2. Movement
3. Transmissibility
   - Infectious period
   - Mosquito spp./strain
   - Mosquito abundance
   - Vector competence



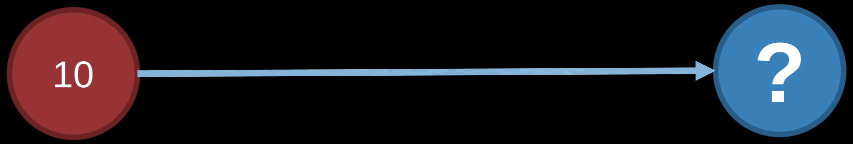
Model

Probability of local transmission

$$p_{AUTO}(i,m) = 1 - \prod_{s \in S} \left(1 - p_{i,s,m} + p_{i,s,m} e^{R_{0i,m}^{HM}\left(e^{-R_{0i,m}^{MH}} - 1\right)} \right)^{I_{s,m} D}$$

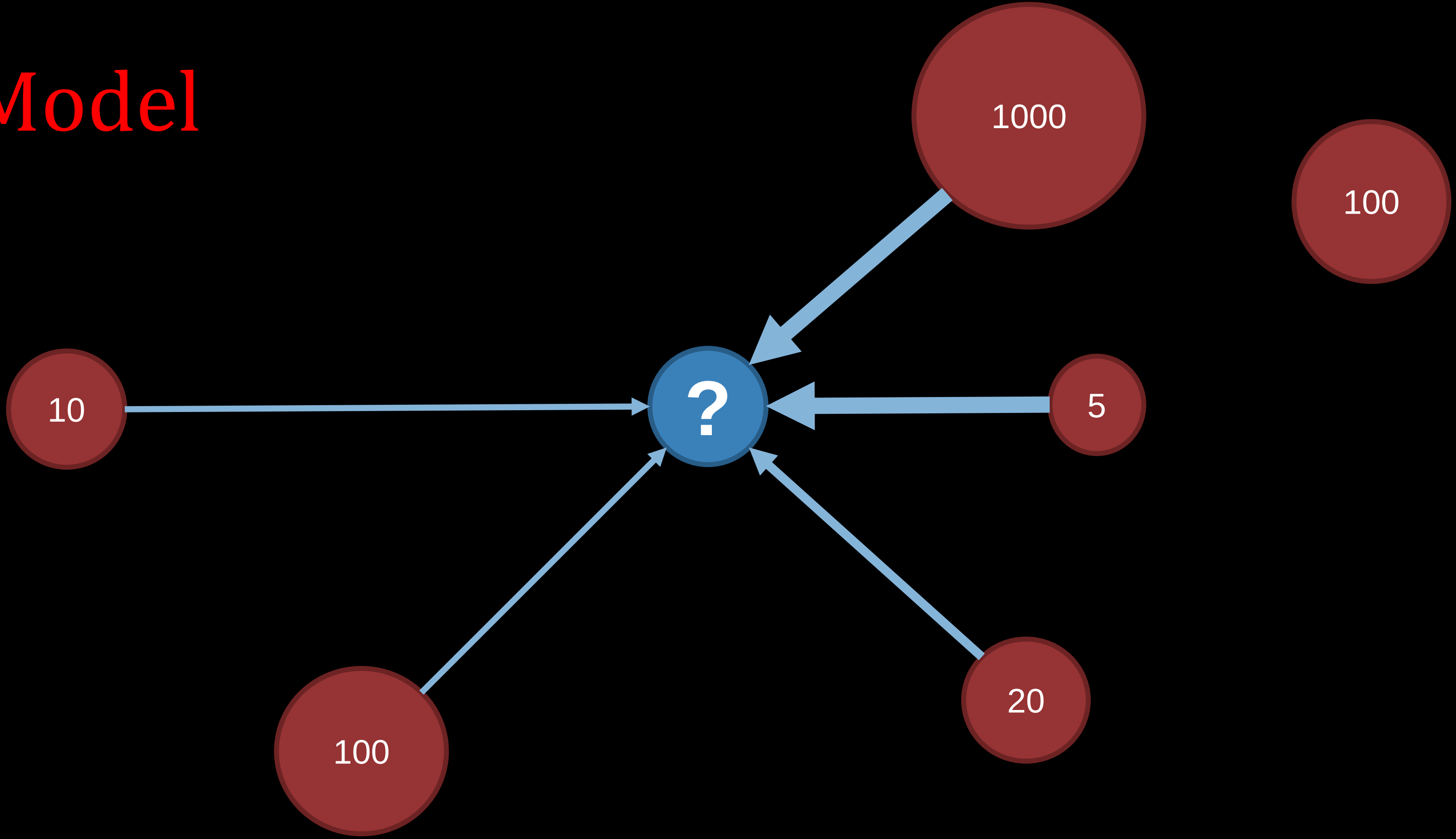
Johansson et al., *PLOS One*, 2014

Model



Johansson et al., *PLOS One*, 2014

Model

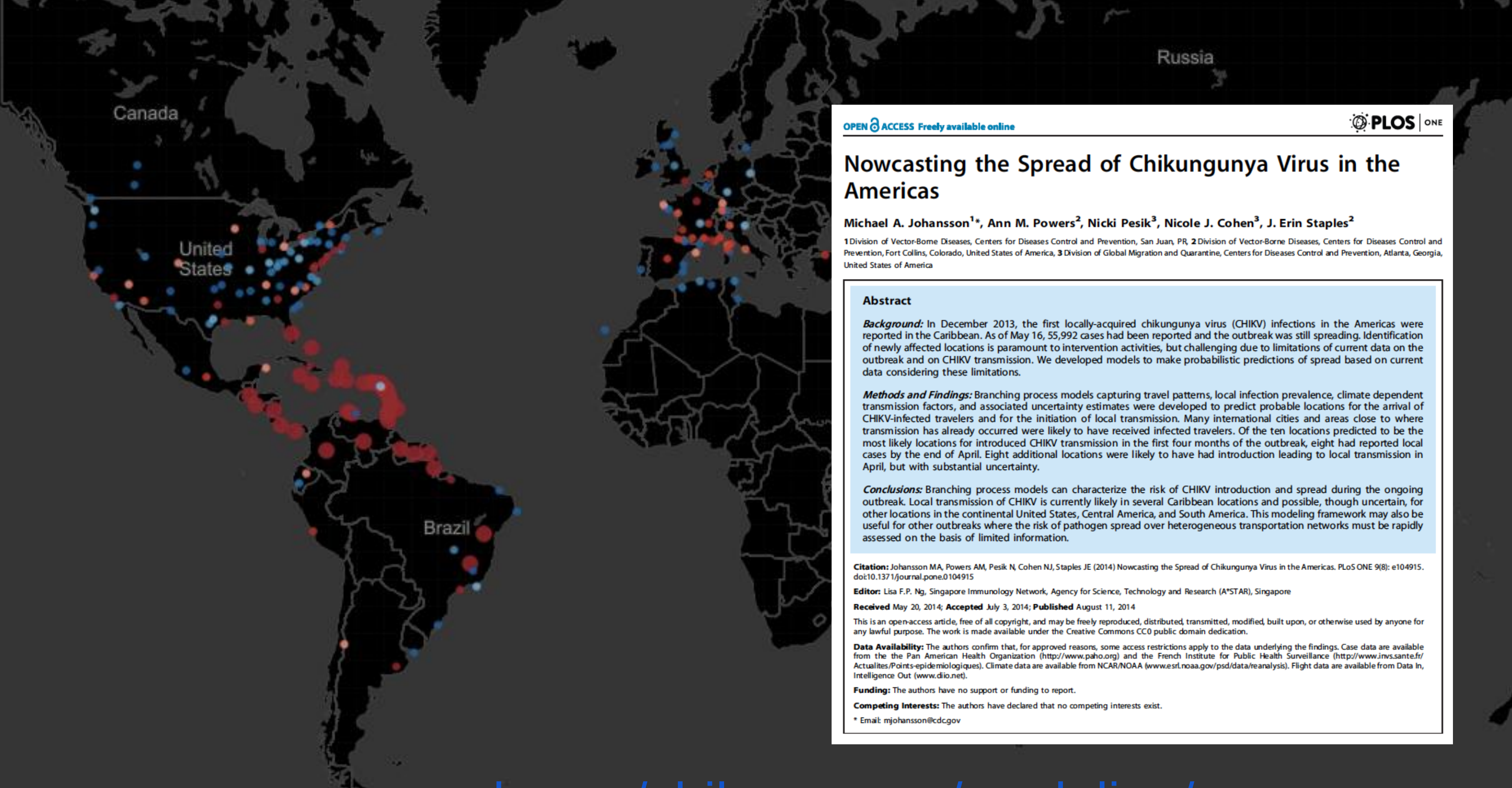


Johansson et al., *PLOS One*, 2014

Evaluation

Key characteristics

- Make predictions public
- Use a baseline
- Evaluate on external data
- Estimate accuracy
- Compare uncertainty



OPEN ACCESS Freely available online

PLOS | ONE

Nowcasting the Spread of Chikungunya Virus in the Americas

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Abstract

Background: In December 2013, the first locally-acquired chikungunya virus (CHIKV) infections in the Americas were reported in the Caribbean. As of May 16, 55,992 cases had been reported and the outbreak was still spreading. Identification of newly affected locations is paramount to intervention activities, but challenging due to limitations of current data on the outbreak and on CHIKV transmission. We developed models to make probabilistic predictions of spread based on current data considering these limitations.

Methods and Findings: Branching process models capturing travel patterns, local infection prevalence, climate dependent transmission factors, and associated uncertainty estimates were developed to predict probable locations for the arrival of CHIKV-infected travelers and for the initiation of local transmission. Many international cities and areas close to where transmission has already occurred were likely to have received infected travelers. Of the ten locations predicted to be the most likely locations for introduced CHIKV transmission in the first four months of the outbreak, eight had reported local cases by the end of April. Eight additional locations were likely to have had introduction leading to local transmission in April, but with substantial uncertainty.

Conclusions: Branching process models can characterize the risk of CHIKV introduction and spread during the ongoing outbreak. Local transmission of CHIKV is currently likely in several Caribbean locations and possible, though uncertain, for other locations in the continental United States, Central America, and South America. This modeling framework may also be useful for other outbreaks where the risk of pathogen spread over heterogeneous transportation networks must be rapidly assessed on the basis of limited information.

Citation: Johansson MA, Powers AM, Pesik N, Cohen NJ, Staples JE (2014) Nowcasting the Spread of Chikungunya Virus in the Americas. PLoS ONE 9(8): e104915. doi:10.1371/journal.pone.0104915

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Data Availability: The authors confirm that, for approved reasons, some access restrictions apply to the data underlying the findings. Case data are available from the the Pan American Health Organization (http://www.paho.org) and the French Institute for Public Health Surveillance (http://www.invs.sante.fr/Actualites/Points-epidemiologiques). Climate data are available from NCAR/NOAA (www.esrl.noaa.gov/psd/data/reanalysis). Flight data are available from Data In, Intelligence Out (www.diio.net).

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Competing Interests: The authors have declared that no competing interests exist.

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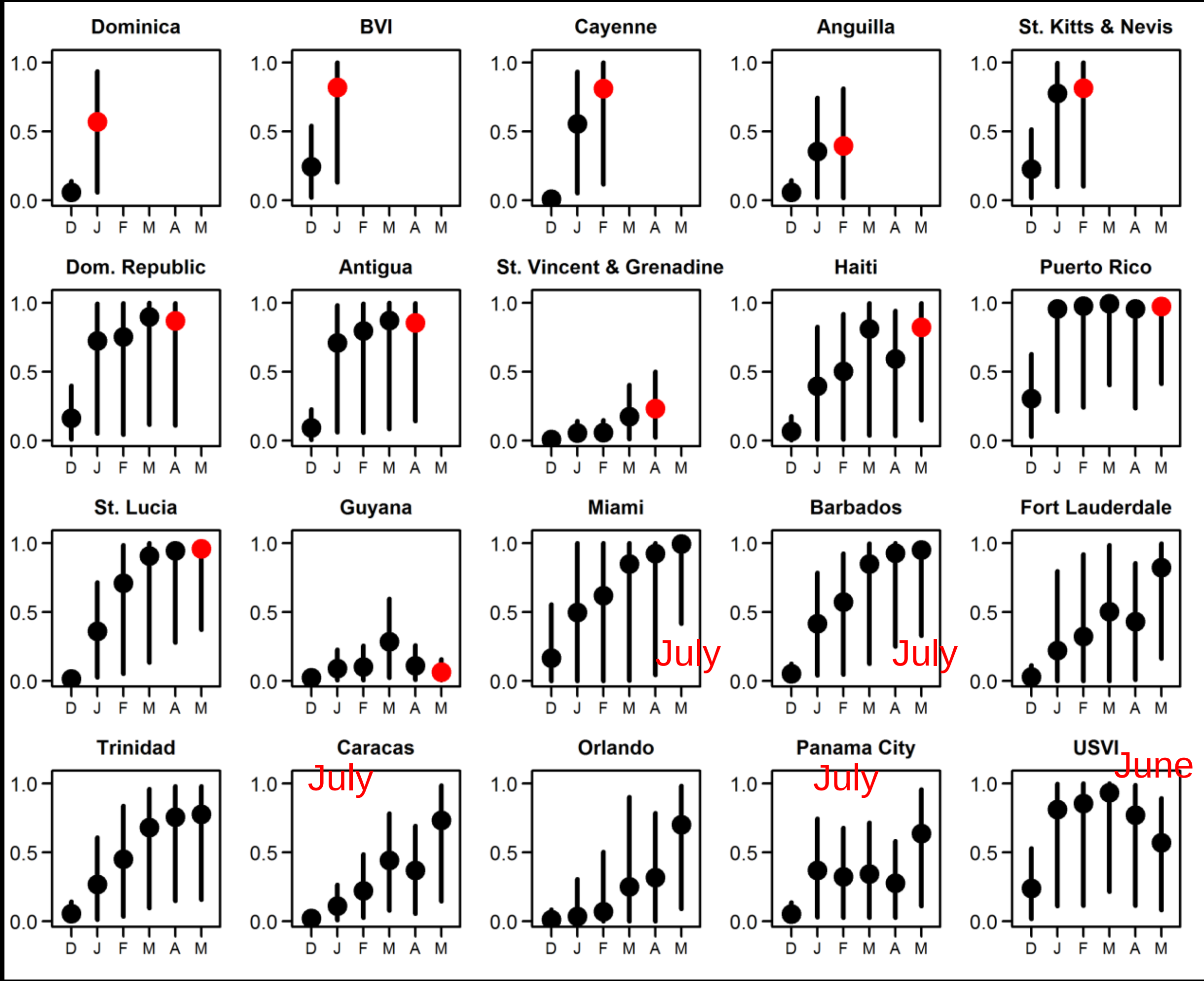
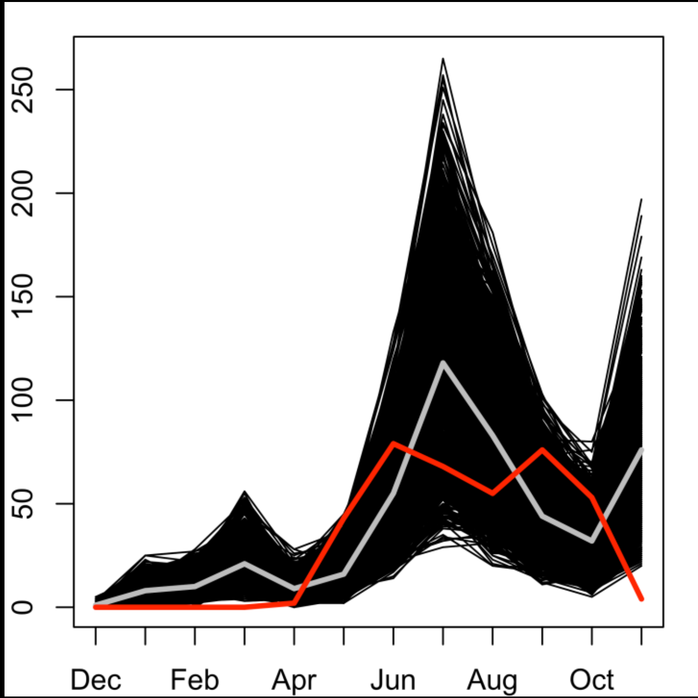
www.cdc.gov/chikungunya/modeling/

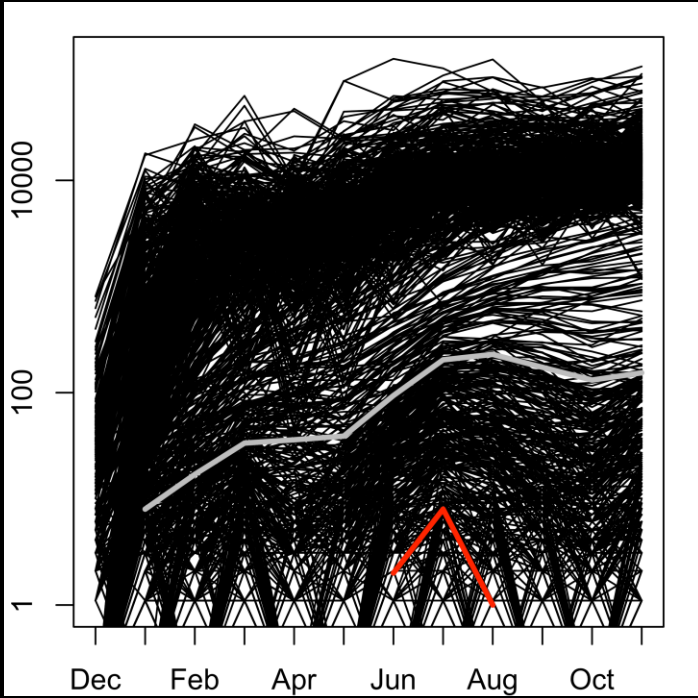
Evaluation


Dominica
BVI
Cayenne
Anguilla
St. Kitts & Nevis
Dom. Republic
Antigua
St. Vincent & Grenadine
Haiti
Puerto Rico
St. Lucia
Guyana
Miami
Barbados
Fort Lauderdale
Trinidad
Caracas
Orlando
Panama City
USVI
July
July
July
July
June
1.0
0.5
0.0
D J F M A M

Evaluation

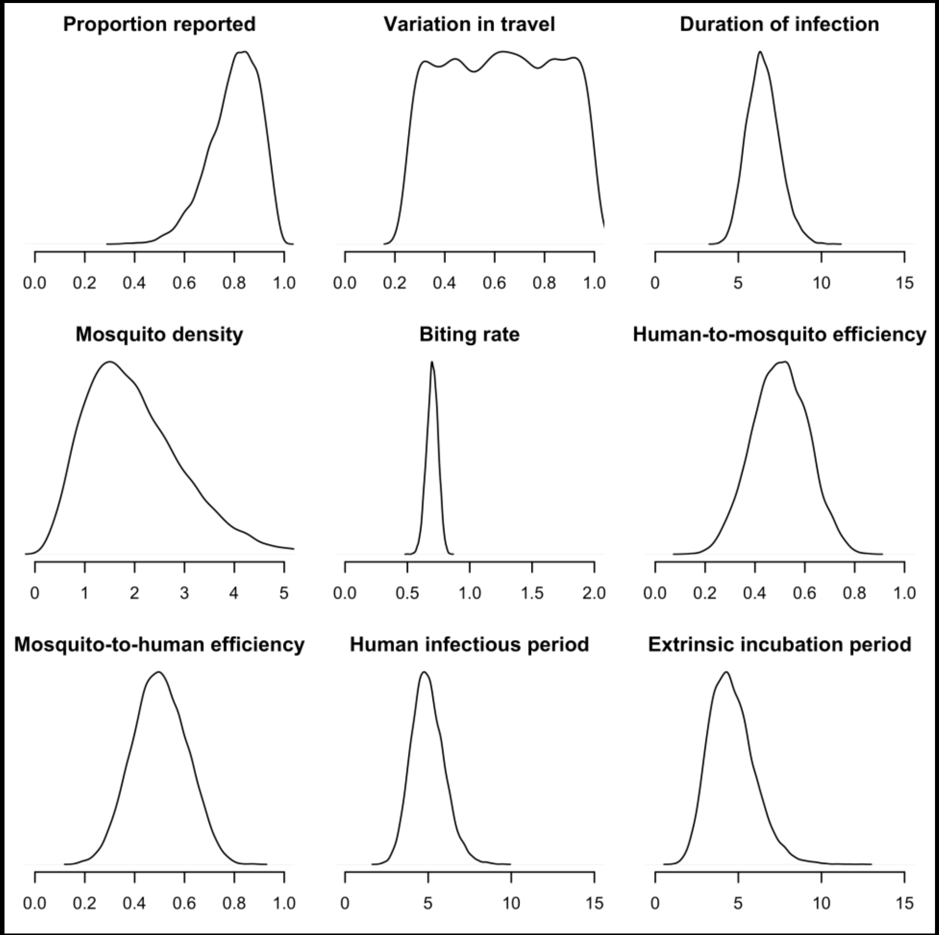


0
50
100
150
200
250
Dec
Feb
Apr
Jun
Aug
Oct

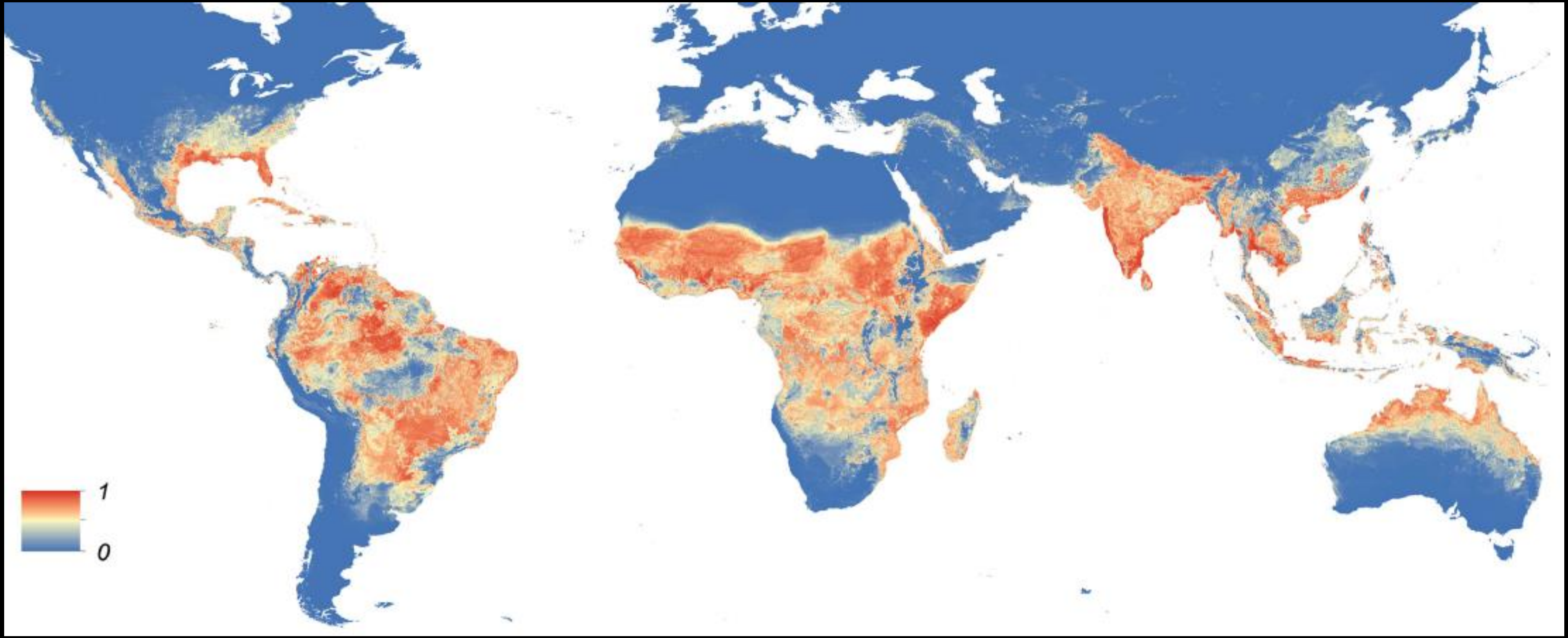


1
100
10000
Dec
Feb
Apr
Jun
Aug
Oct

Uncertainties



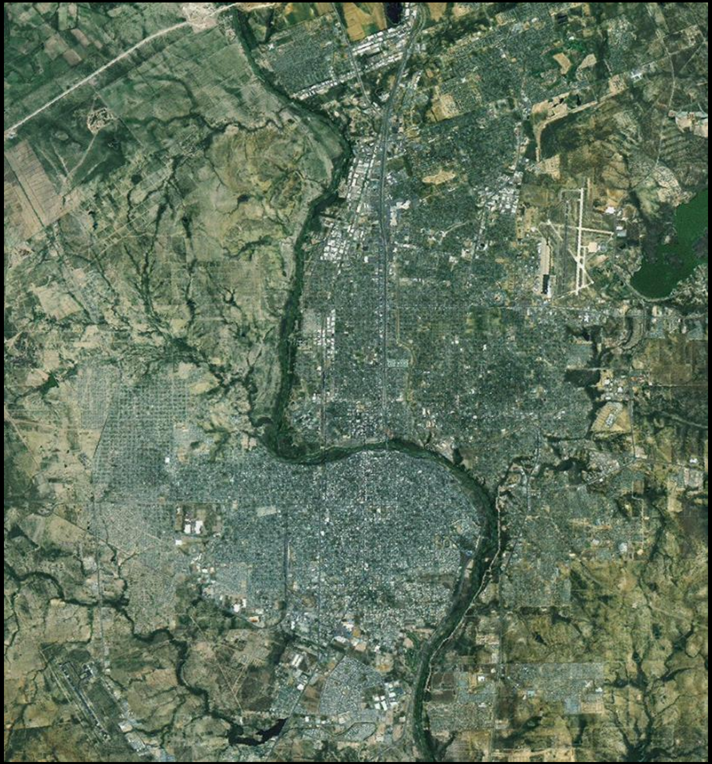
Estimated suitability for *Aedes aegypti*



Kraemer et al, *eLife*, 2015

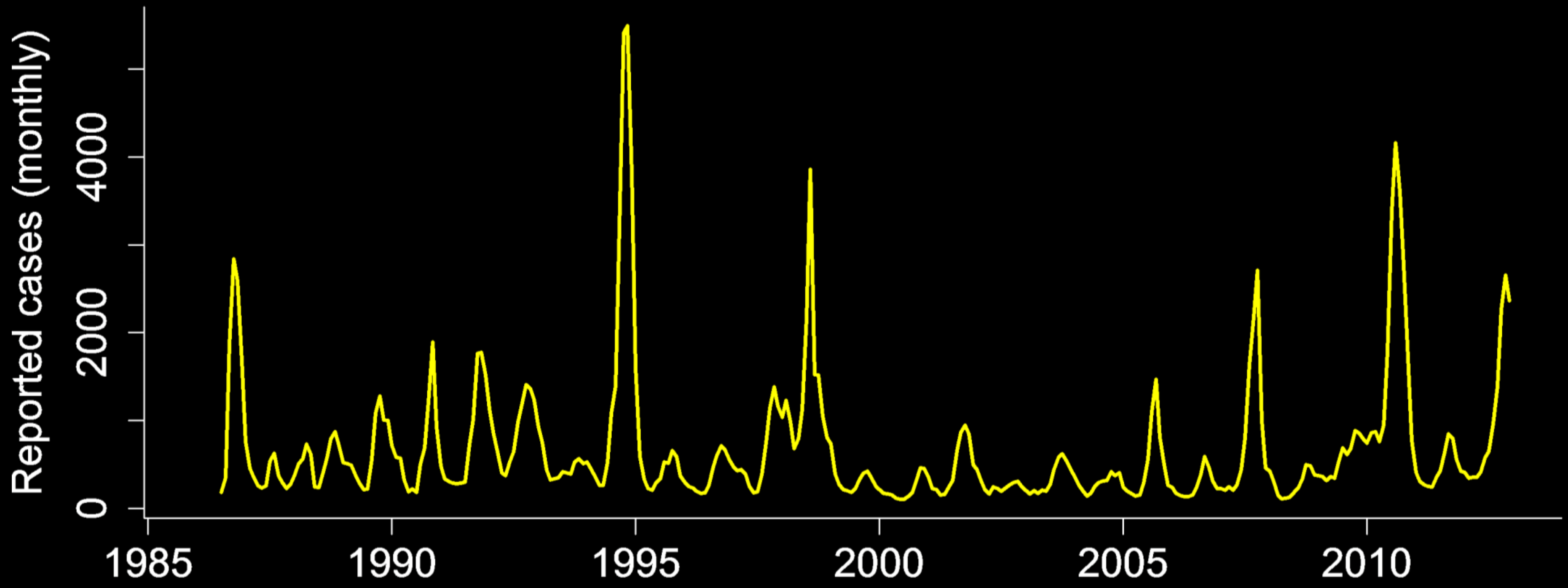
Complex interactions

Nuevo Laredo Mexico	Laredo USA
Recent Infection 16%	Recent Infection 1%
Past Infection 48%	Past Infection 23%
Ae. aegypti index 25%	*Ae. aegypti* index 37%



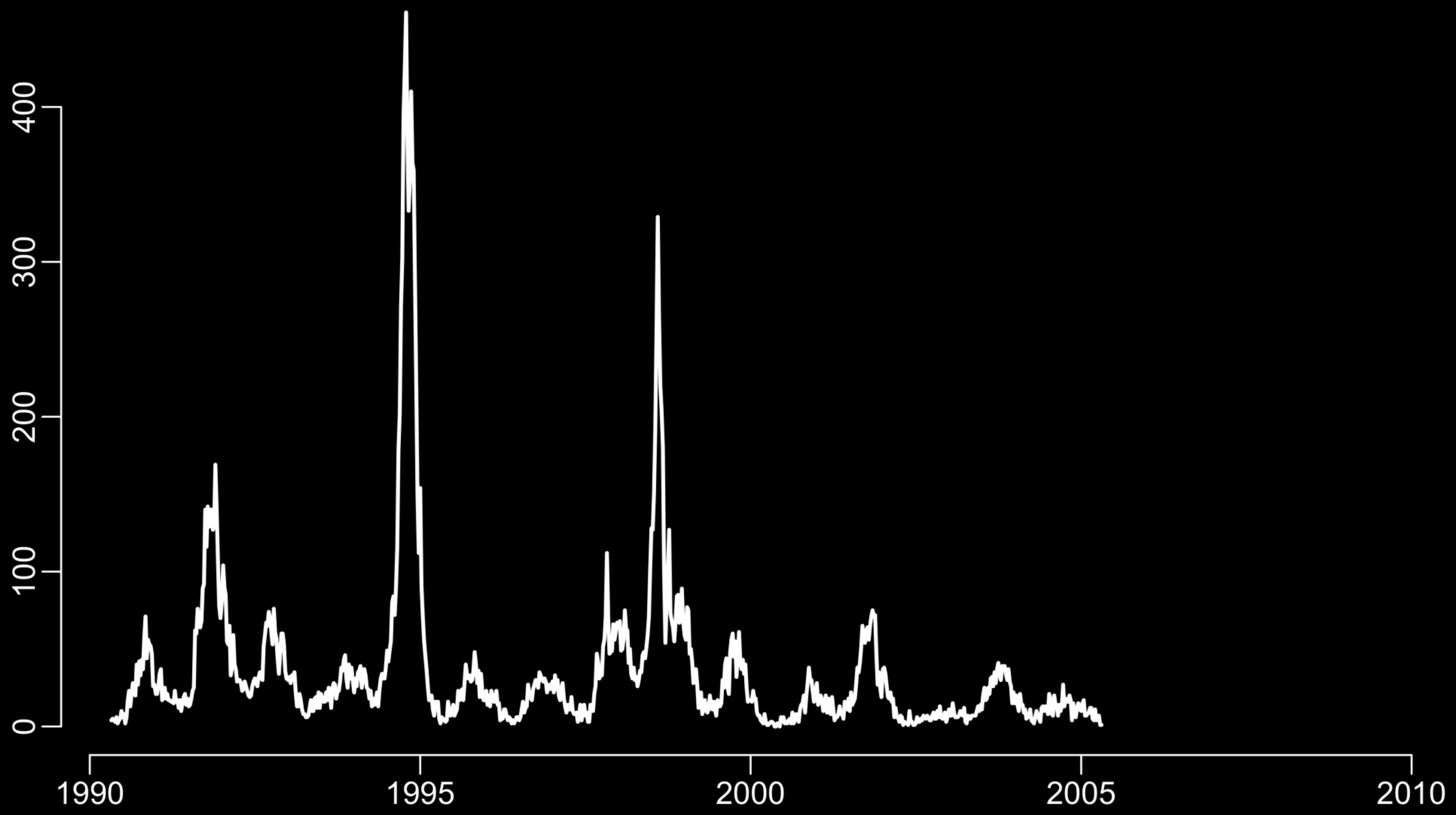
Reiter et al., *EID*, 2003

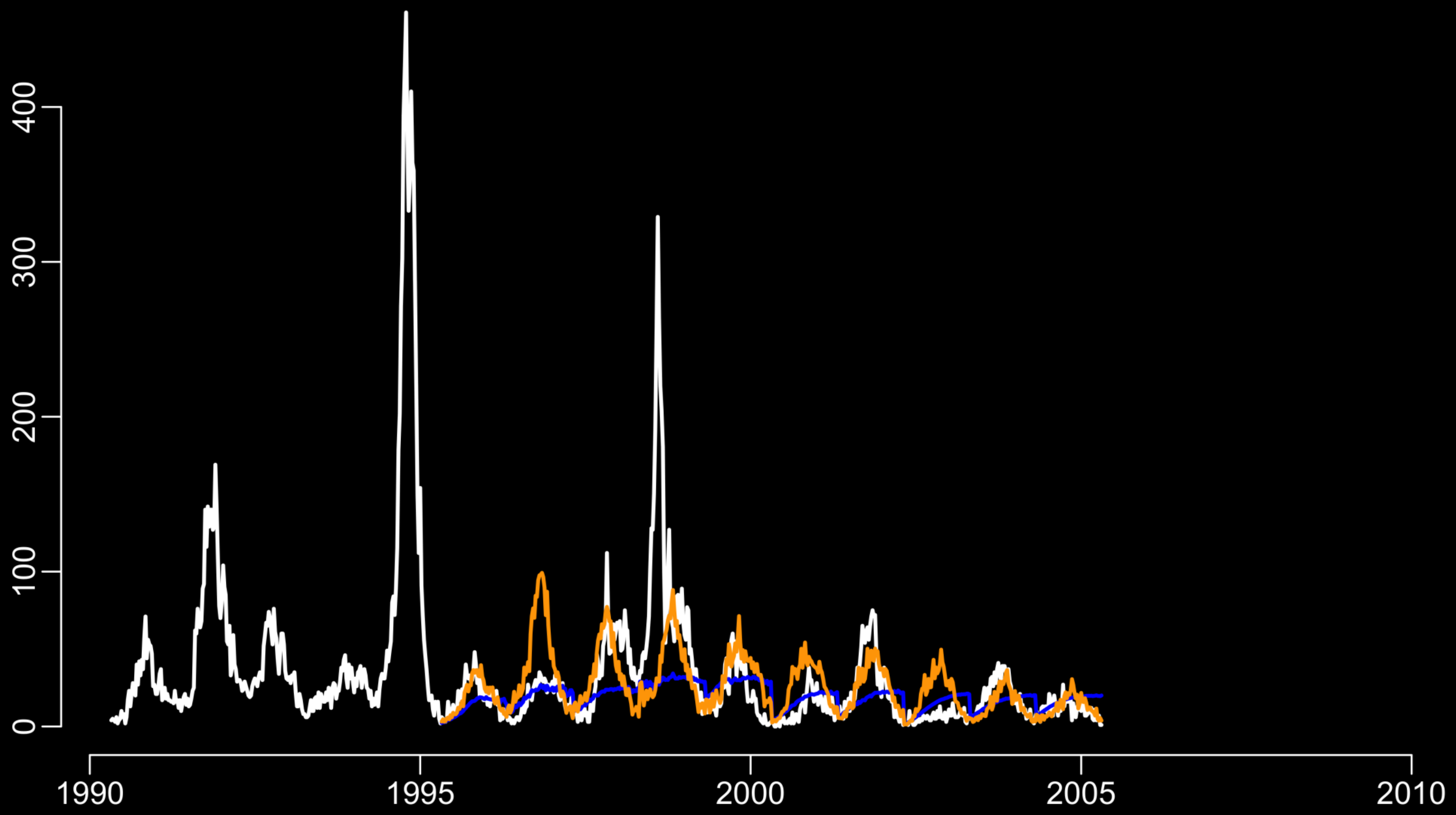
Dengue in Puerto Rico



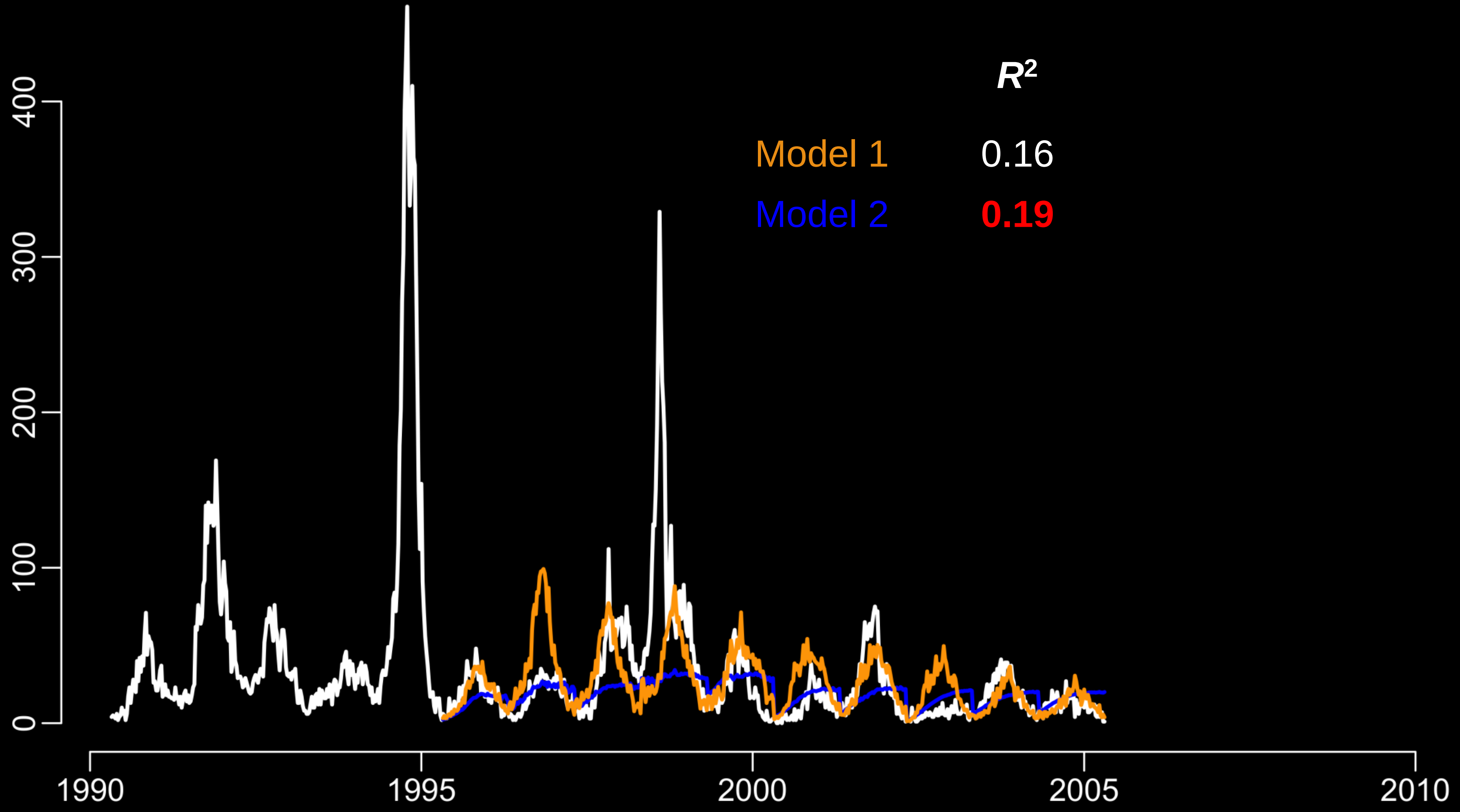
Targets

What will the peak incidence be?

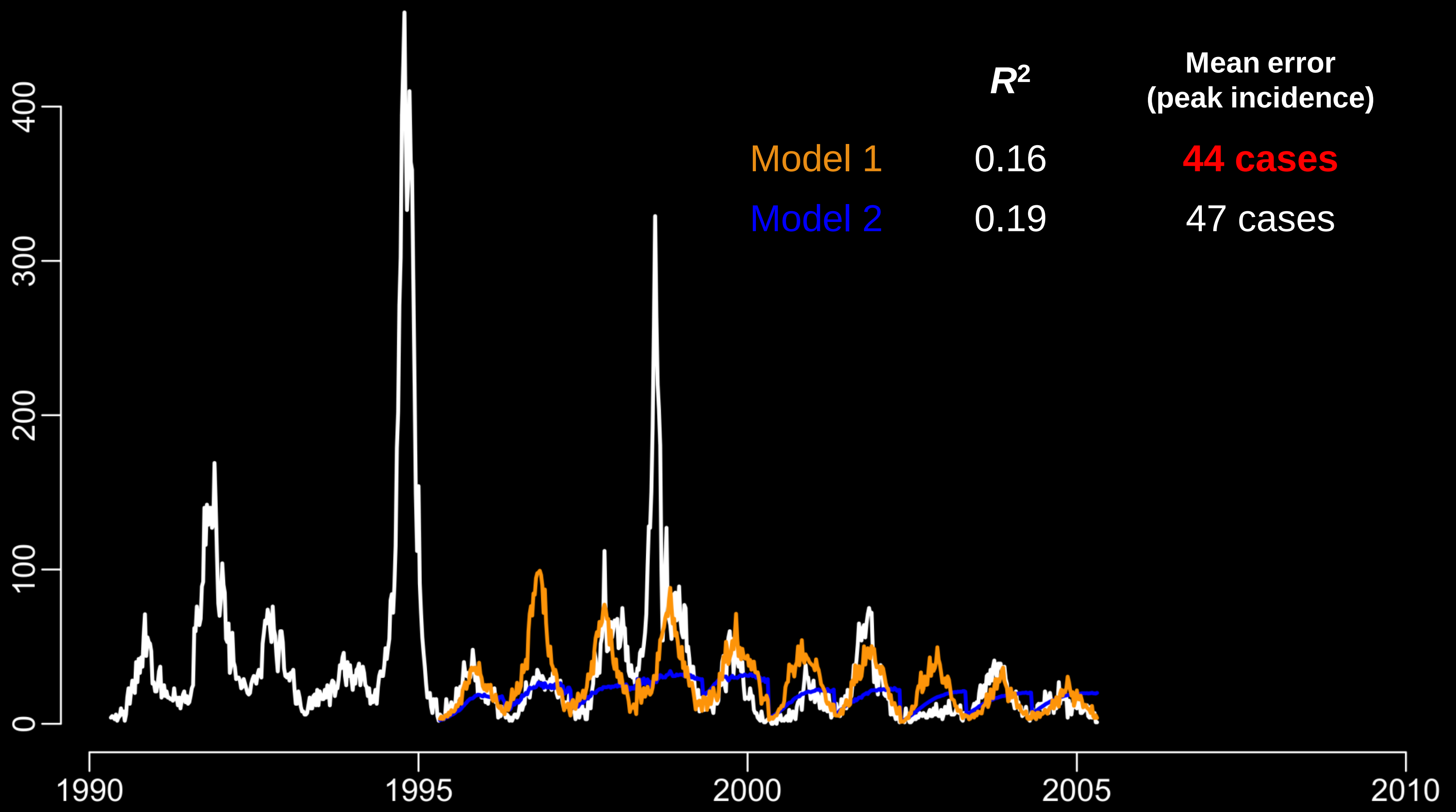

0
100
200
300
400
1990
1995
2000
2005
2010



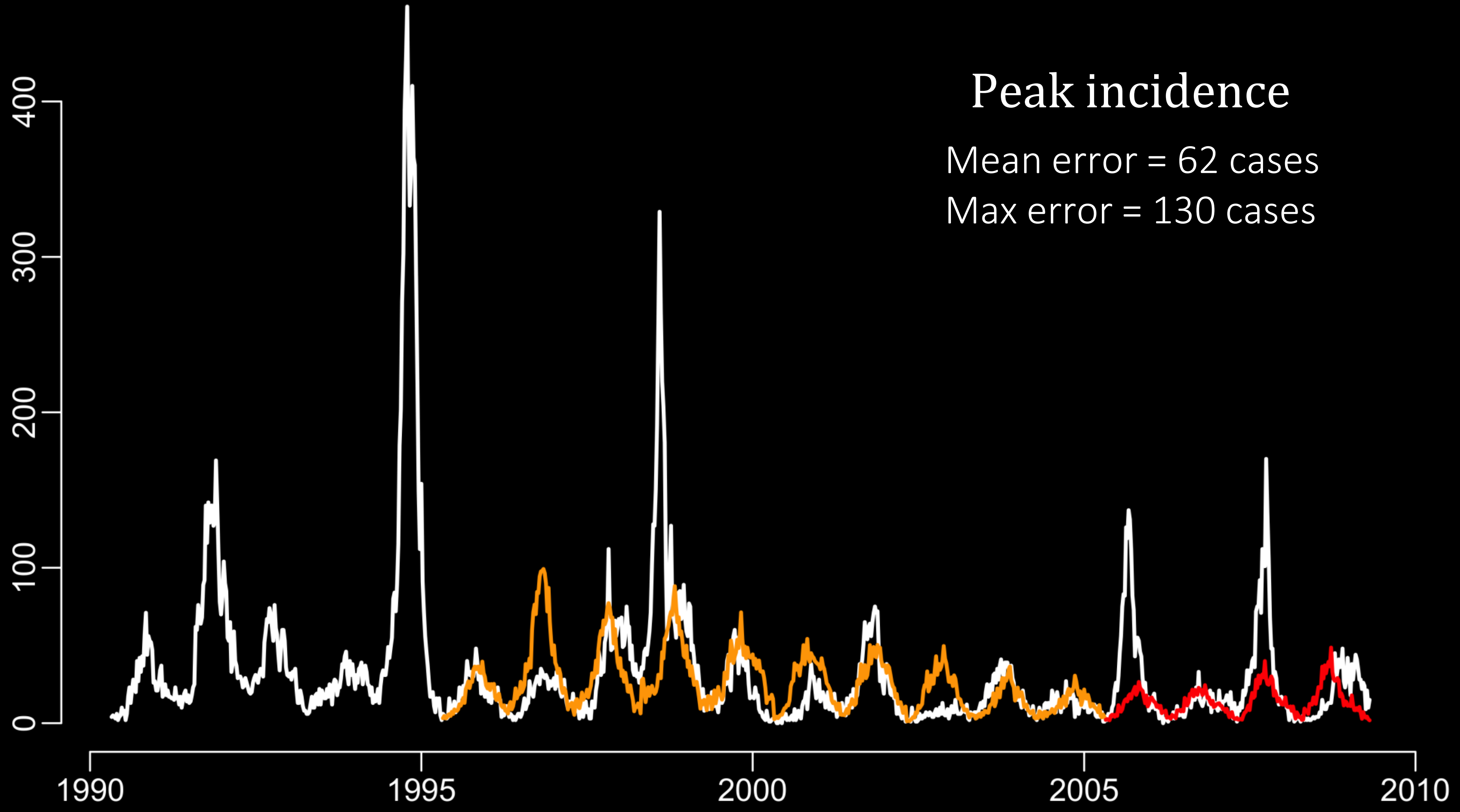
0
100
200
300
400
1990
1995
2000
2005
2010



R^2
Model 1 0.16
Model 2 0.19
0
100
200
300
400
1990
1995
2000
2005
2010



R^2
Mean error
(peak incidence)
Model 1
0.16
44 cases
Model 2
0.19
47 cases
0
100
200
300
400
1990
1995
2000
2005
2010

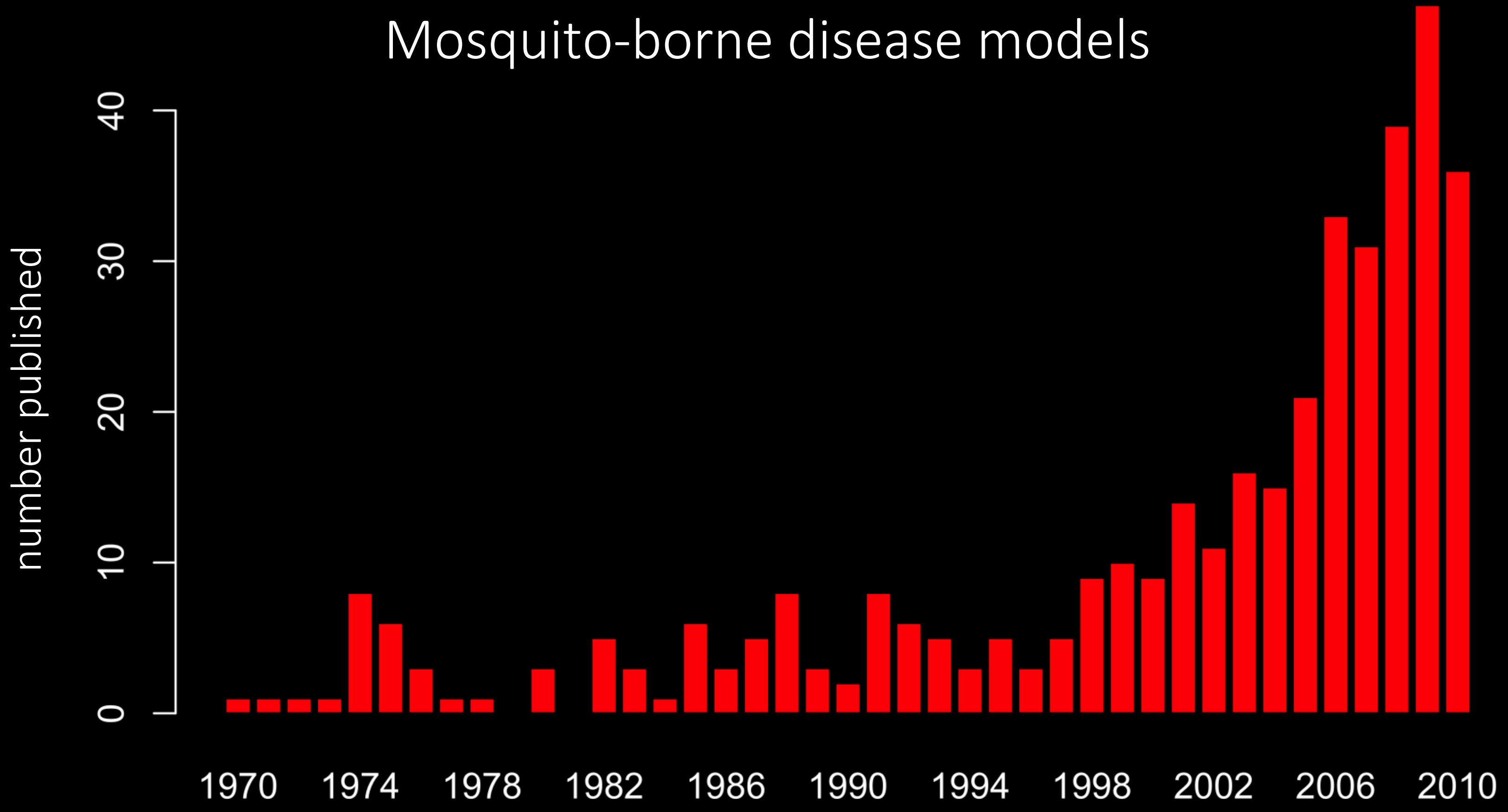


Peak incidence

Mean error = 62 cases

Max error = 130 cases

Mosquito-borne disease models



Reiner, Perkins, et al. *J. R. Soc. Interface* 2013

Dengue Forecasting Project

Targets: Peak incidence, peak timing, and total cases

Data: Public data release: San Juan and Iquitos

(inc. serotype + environmental)

Evaluation: Testing/training, quantitative metrics

Models: Any

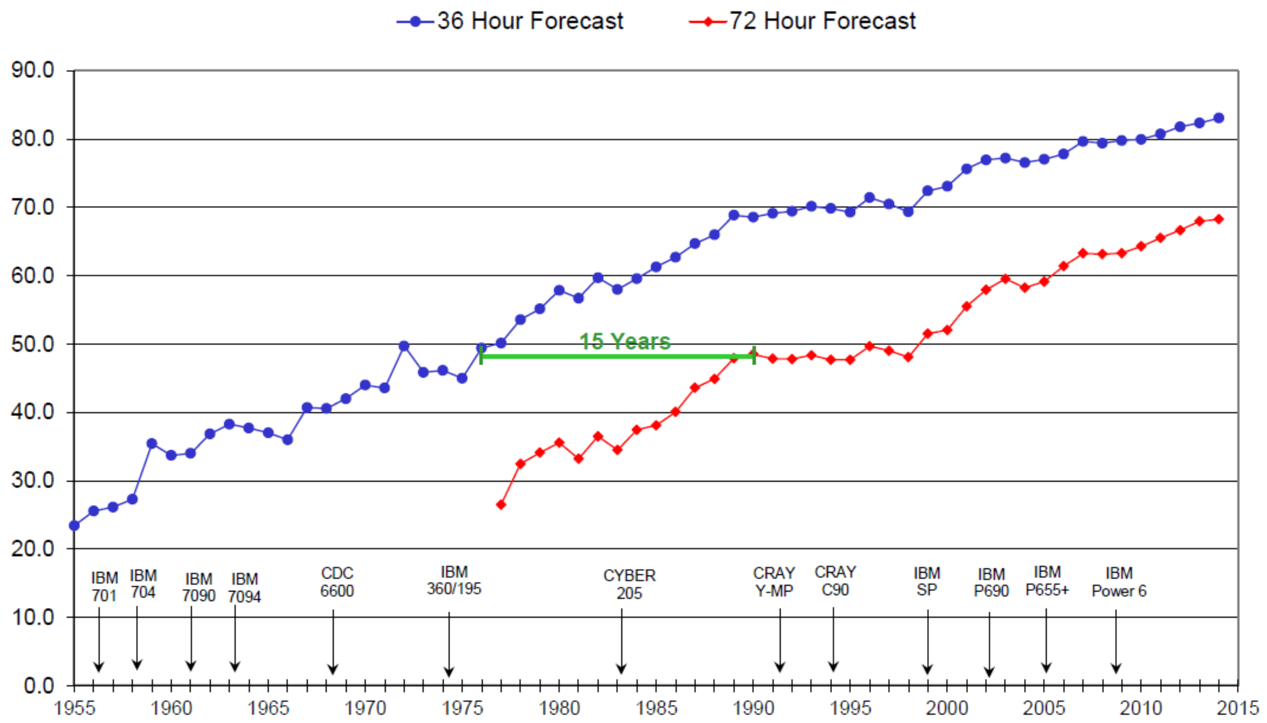
predict.phiresearchlab.org

dengueforecasting.noaa.gov

NCEP Operational Forecast Skill

36 and 72 Hour Forecasts @ 500 MB over North America

[100 * (1-S1/70) Method]



www.nco.ncep.noaa.gov

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