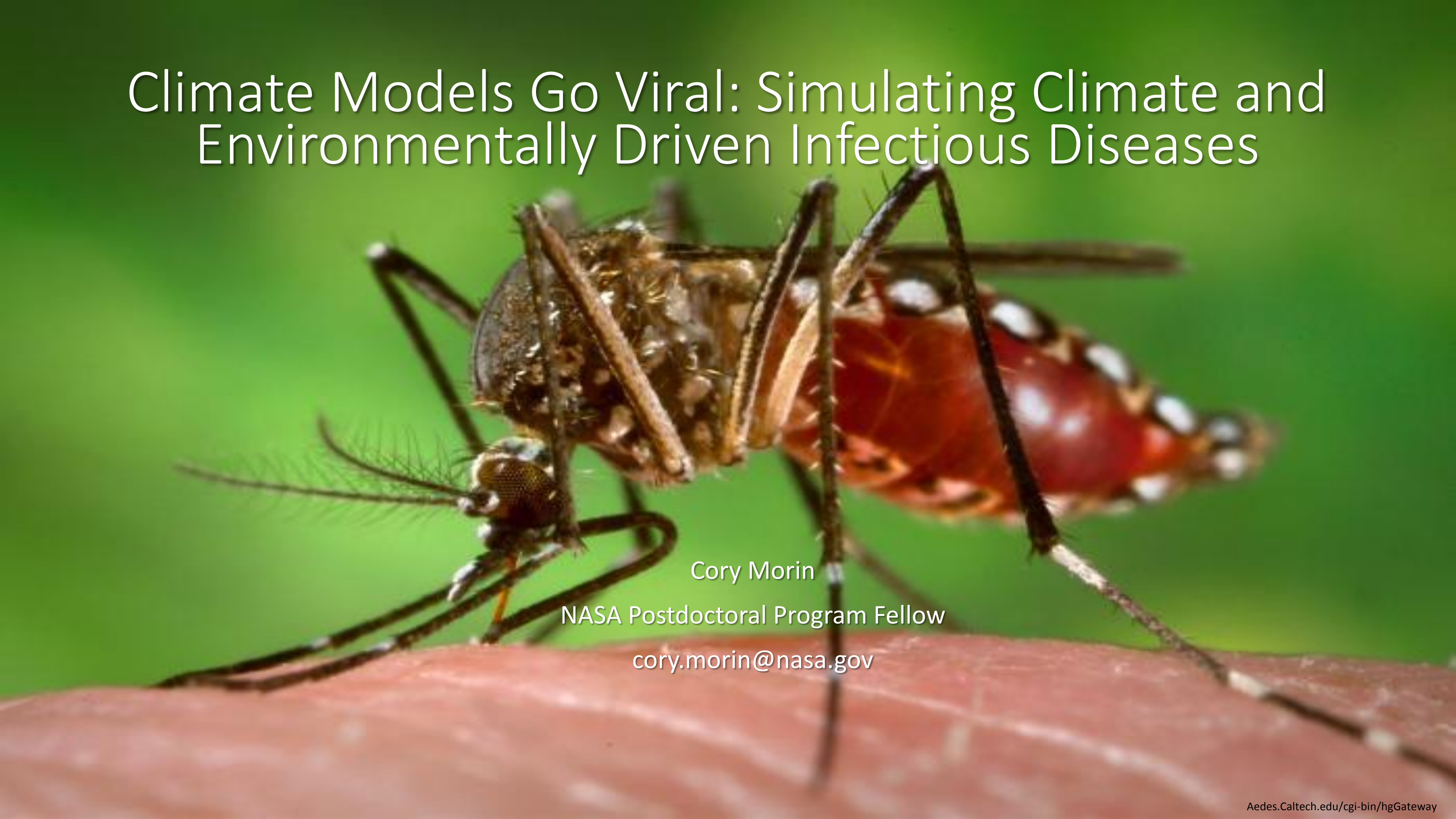
Climate Models Go Viral: Simulating Climate and Environmentally Driven Infectious Diseases



Cory Morin

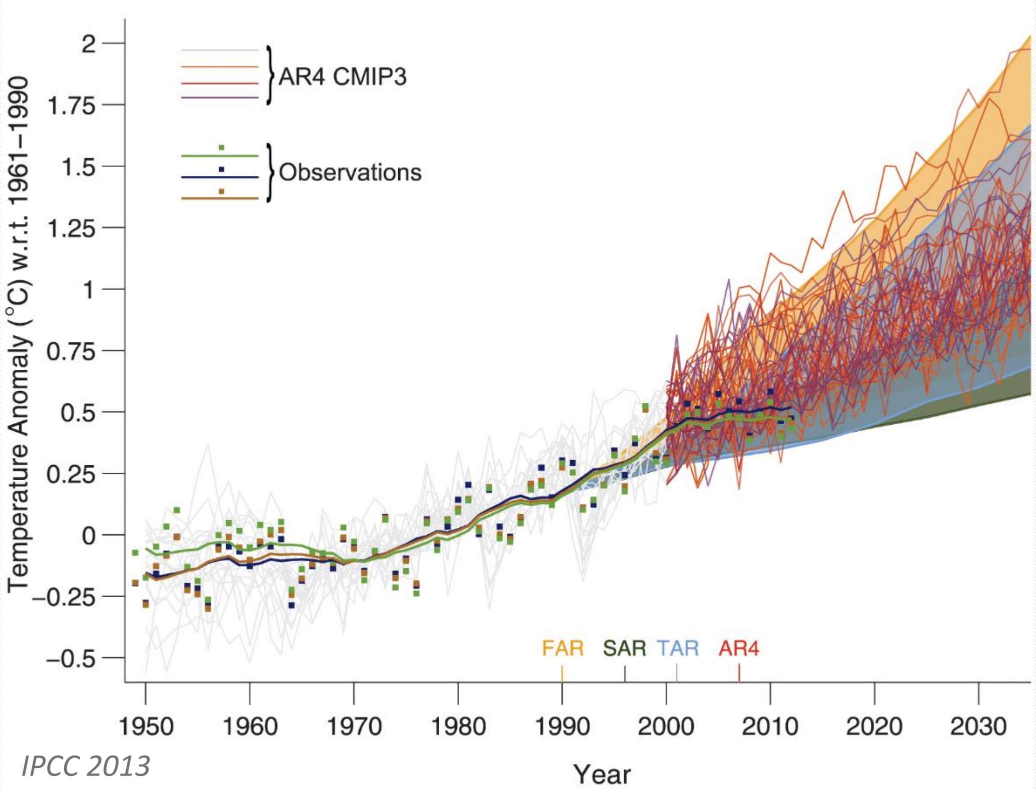
NASA Postdoctoral Program Fellow

cory.morin@nasa.gov

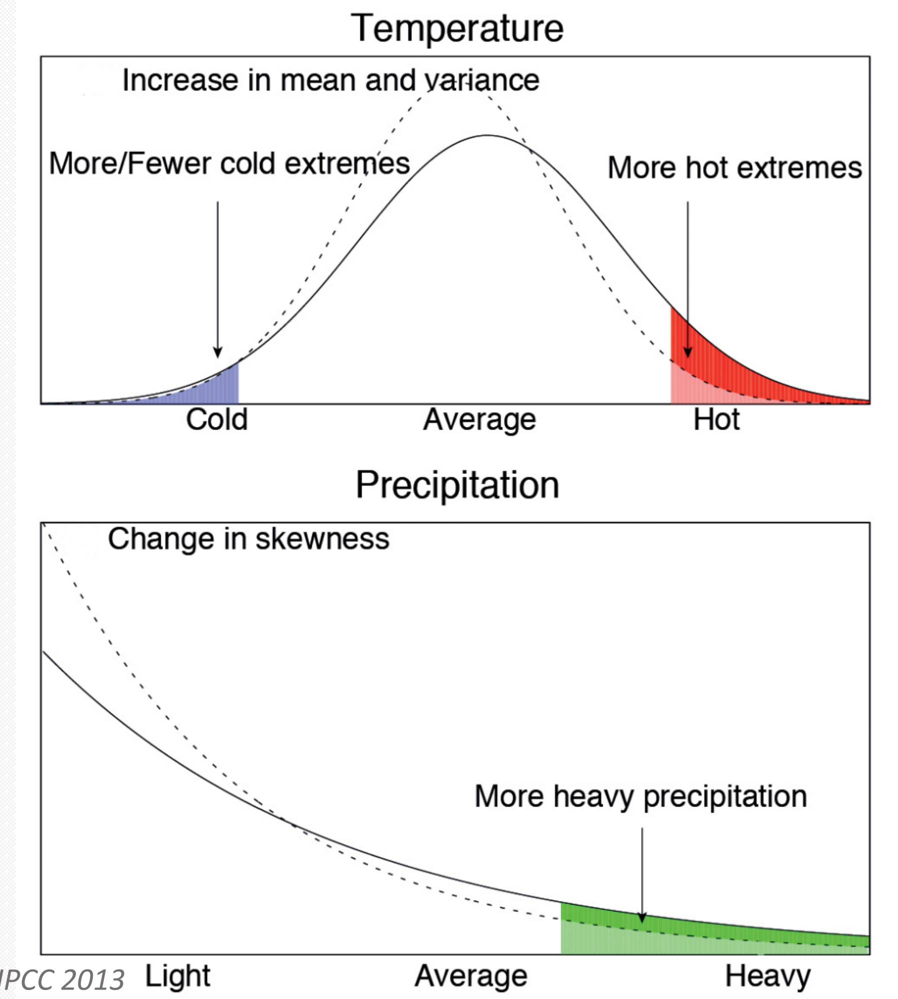
Aedes.Caltech.edu/cgi-bin/hgGateway

Climate Variability and Change

- Shift in mean and variance
- Increase in frequency of extreme conditions



IPCC 2013



IPCC 2013

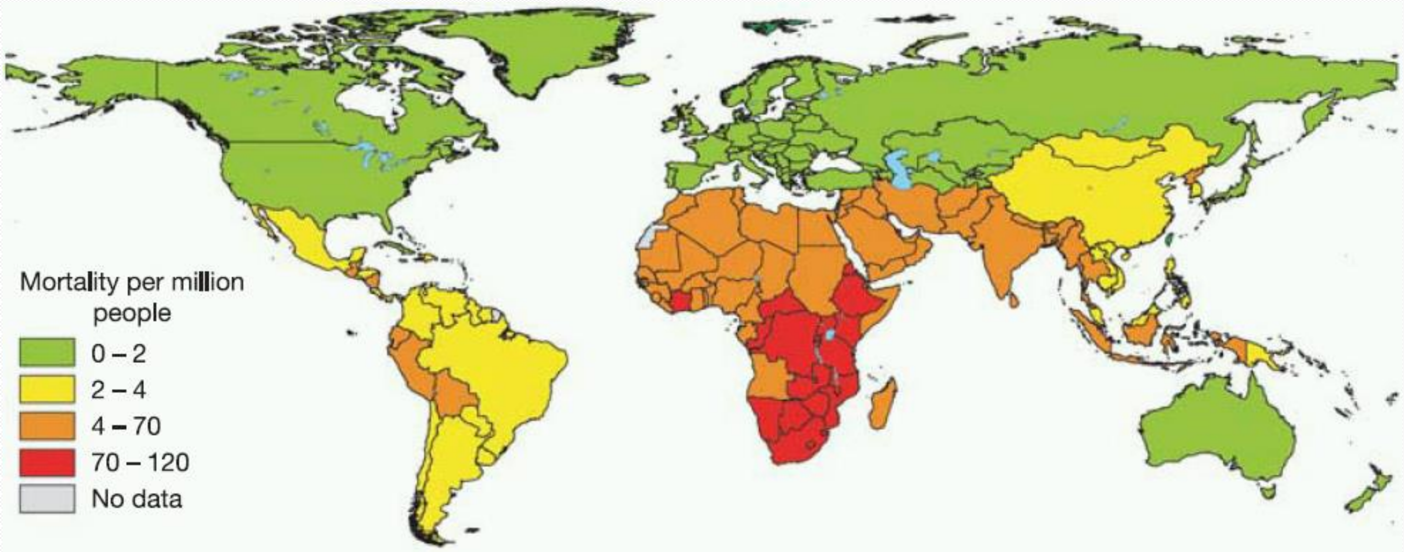
Outline of Presentation

- Background on climate and health
  - Climate change and vulnerability
  - Health effects and disease ecology
- Systems modeling
- Steps in climate and health research
  - Simulation of disease incidence (San Juan, PR)
  - Investigation of outbreaks (Hermosillo, MX)
  - Disease forecasting (San Juan, PR)
  - Projected risk under future climate (Southern US)
- Conclusions and Future work

Climate Change Deaths

- 150,000 lives annually over last 30 years (WHO)
- Who & where? How & why?

WHO estimated mortality attributable to climate change by the year 2000

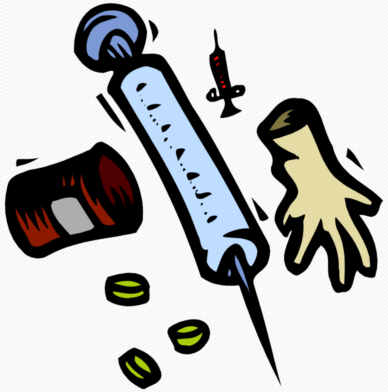


Climate Effects on Human Health

Extreme Temperatures

Extreme Weather

- Flooding
- Hurricanes
- Tornadoes



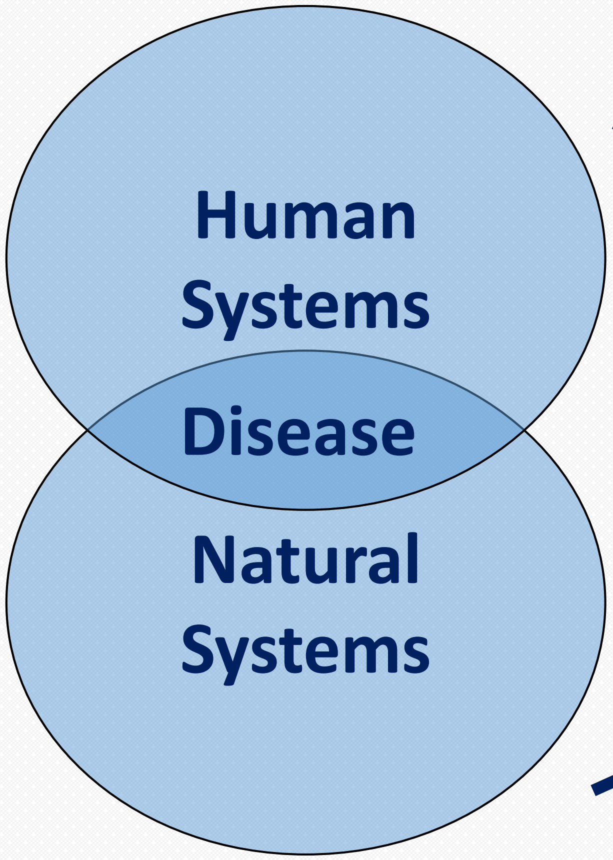
Pathogens

- Vector-borne
- Water-borne
- Air-borne

Air Quality

- Pollen
- Ozone
- Particulate Matter

Interdisciplinary Research



Interdisciplinary Research
Social Science
Epidemiology
Geography
Disease Ecology
Climate Science

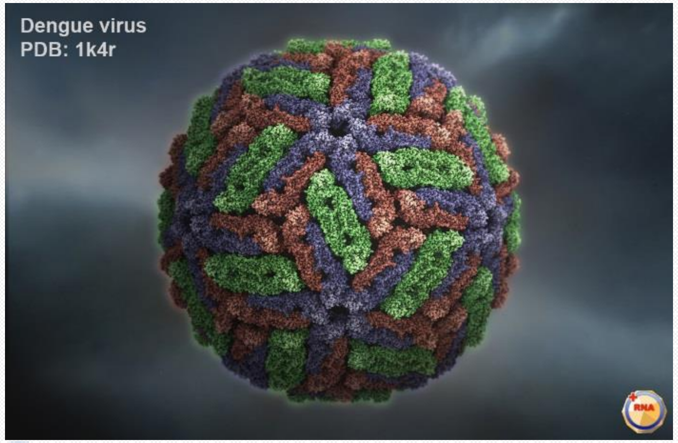
- Risk
- ***V***ulnerability
  - $V = f\,(E, S, A)$
- ***E***xposure
- ***S***ensitivity
- ***A***daptive Capacity

} Environmental Stimulus

} Social Resilience

Challenges in Climate and Health Research

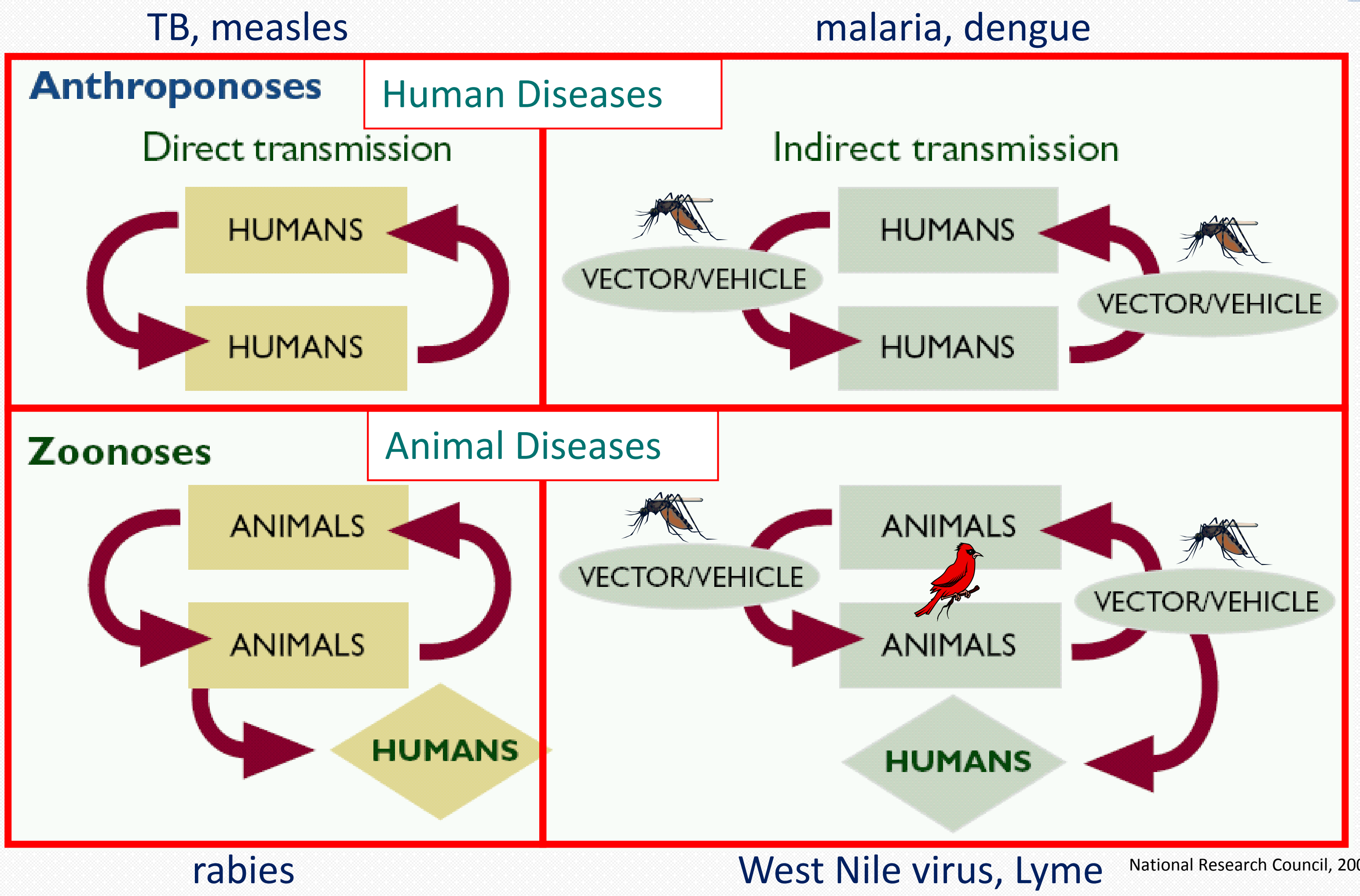
- Reporting problems
  - Misdiagnosis
  - Subclinical cases
  - Reporting errors/bias
  - Availability of data



- Knowledge gaps
  - Incubation periods
  - Transmission probabilities
  - Evolution and adaption of virus and human immunity

- Human vs. climate influences
  - Socioeconomic status
  - Microclimatic influences
  - Human adaptions to climate

Infectious Disease Transmission Cycles



National Research Council, 2001

Vector-borne Diseases in the US

Dengue Viruses

- Annually ~ 96 million cases of symptomatic disease (WHO)
- Endogenous transmission in Texas and Florida
- Symptoms: muscle and bone ache, fever, and hemorrhagic manifestations in rare cases

Lyme Disease

- Transmitted by the tick *Ixodes scapularis* (*Ixodes pacificus)*
- Symptoms: rash, joint pain, headaches, arthritis
- 11-30,000 cases per year in US

West Nile Virus

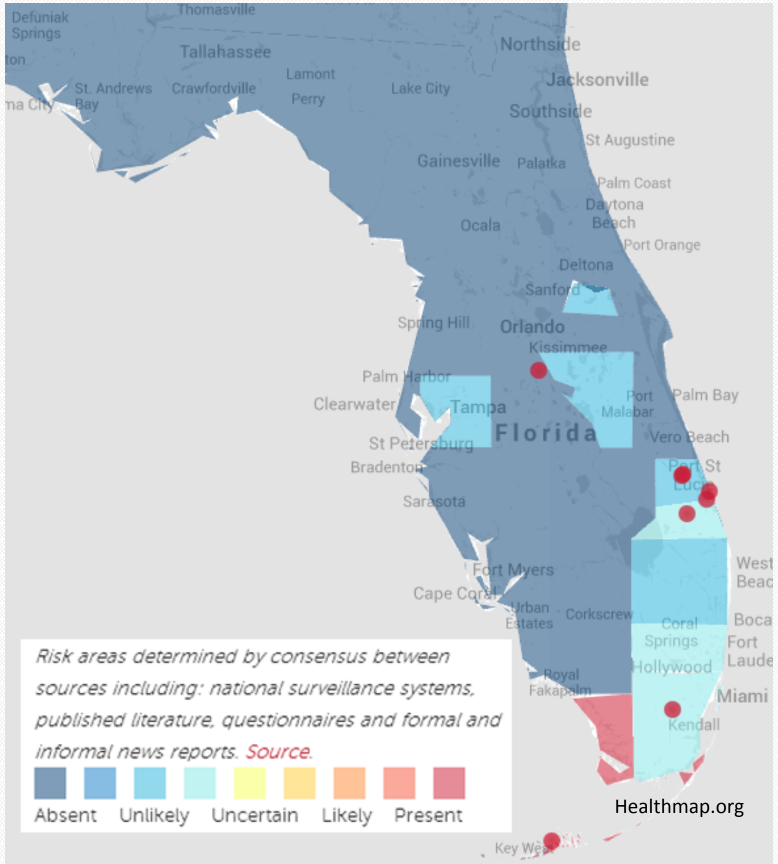
- In the US: 39,557 cases of disease and 1,668 deaths (CDC, 1999-2013)
- Disease ranges from mild fever to encephalitis and meningitis
- Now endemic in most of the United States

Chikungunya Virus

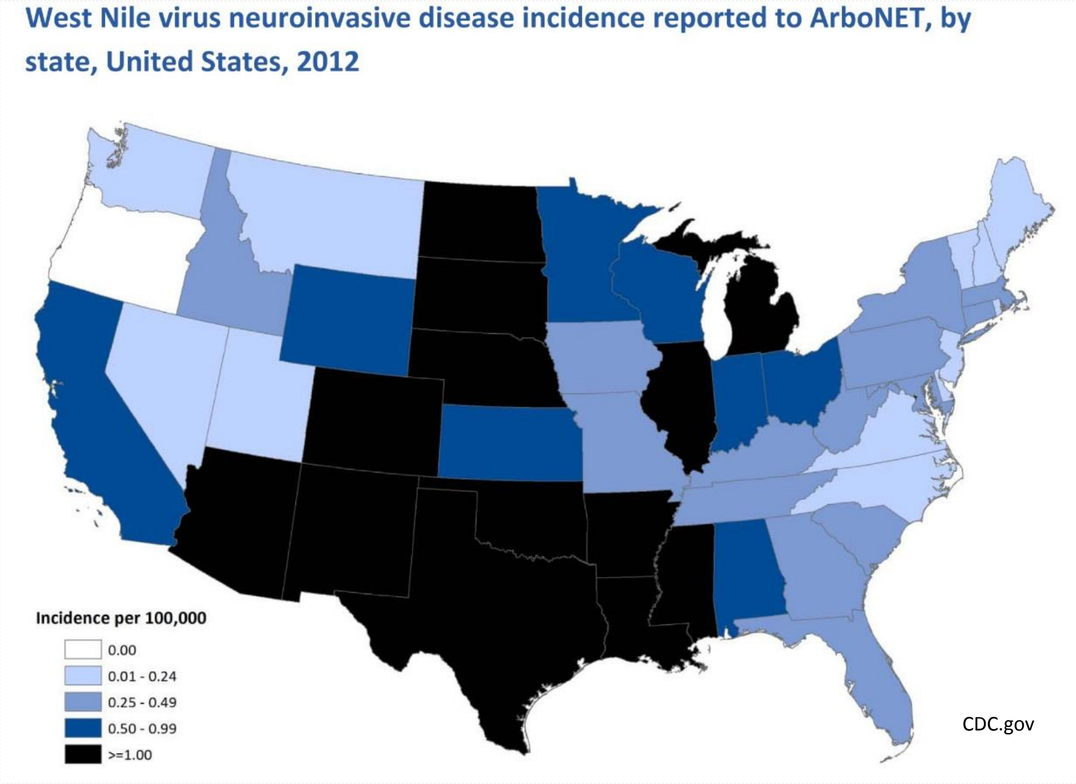
- In 2013 first locally acquired cases reported in the Americas
- Symptoms include fever, joint pain, headaches, and rash

How does weather/climate affect mosquito-borne disease risk and can it be predited?

- Increases in the range of diseases

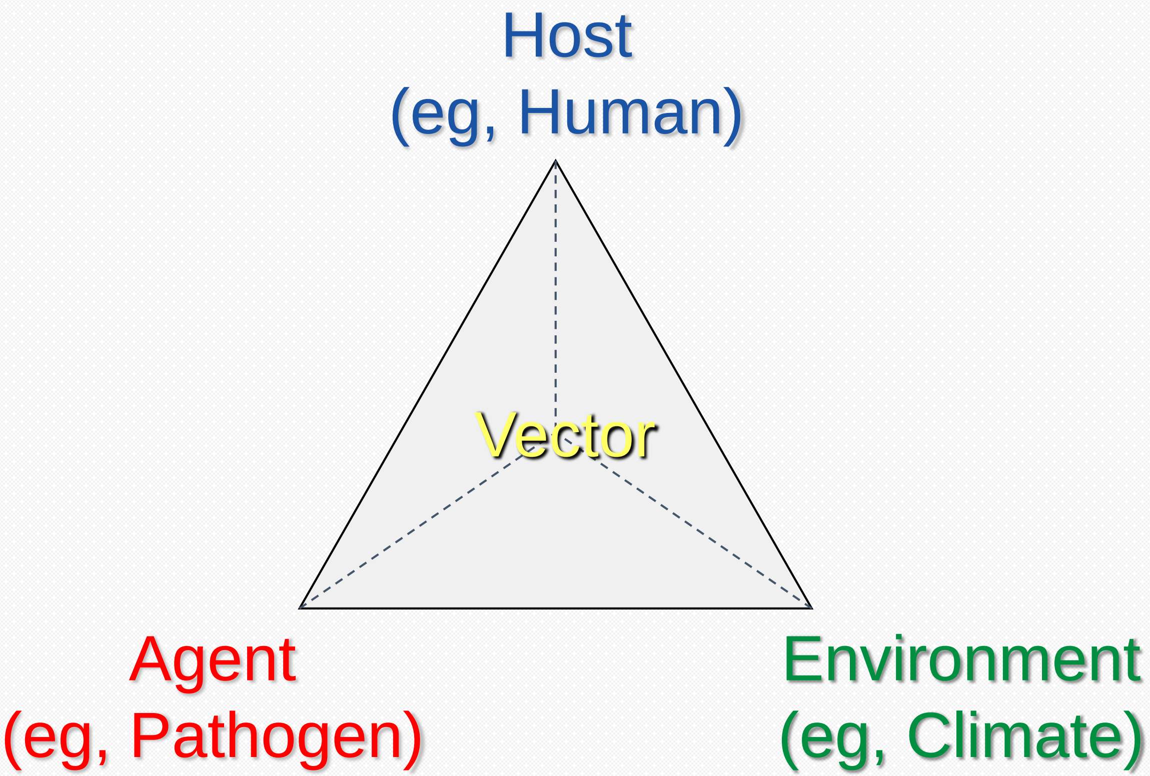


- Increases in the seasonality of diseases



Epidemiologic Triangle of Disease (Vector-borne Diseases)

- A *multi-factorial* relationship between hosts, agents, vectors and environment



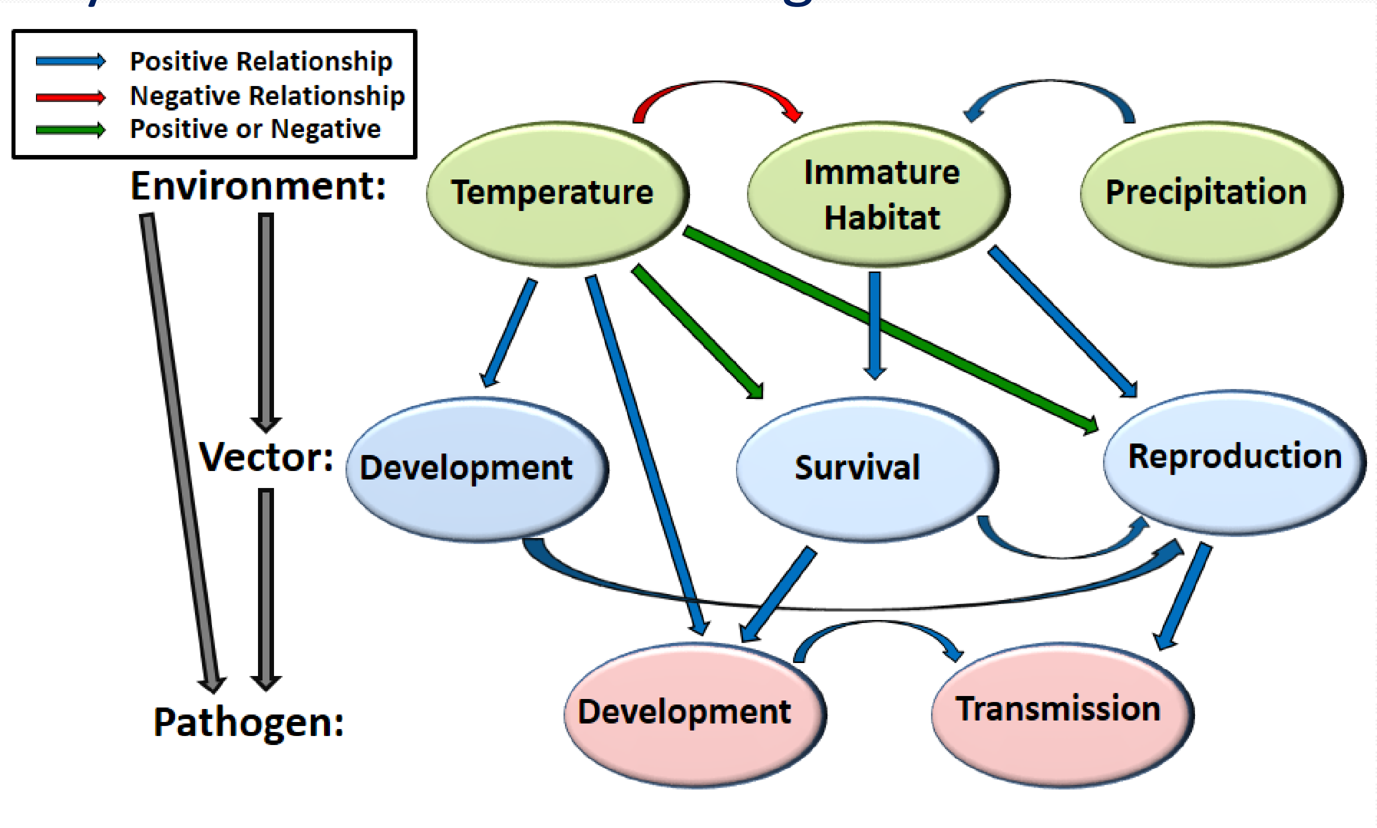
Systems Modeling

"A system is an interconnected set of elements that is coherently organized in a way that achieves something."

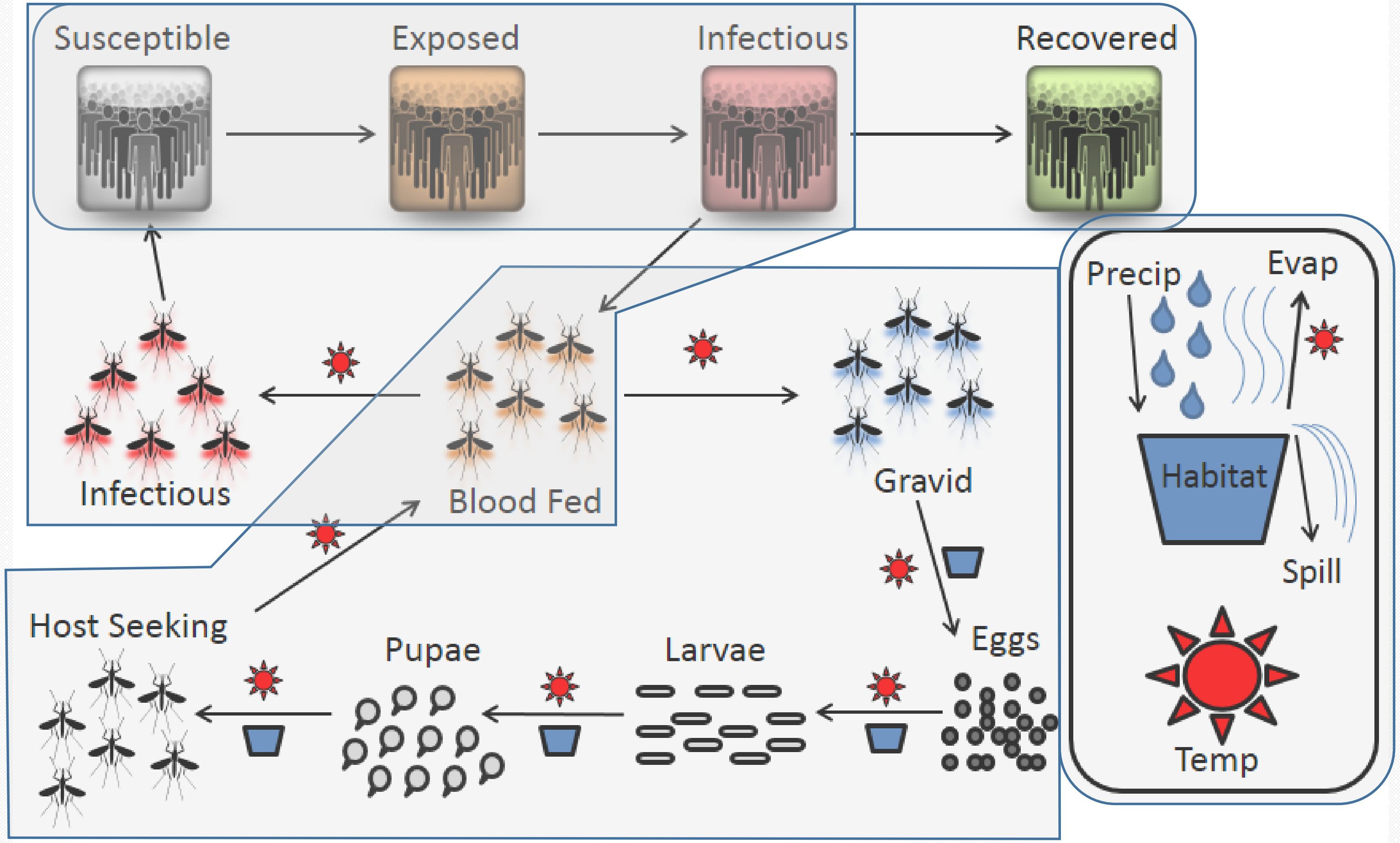
- Donella H. Meadows

- Why this method?

- Allows us to consider multiple elements of disease ecology and nonlinear relationships



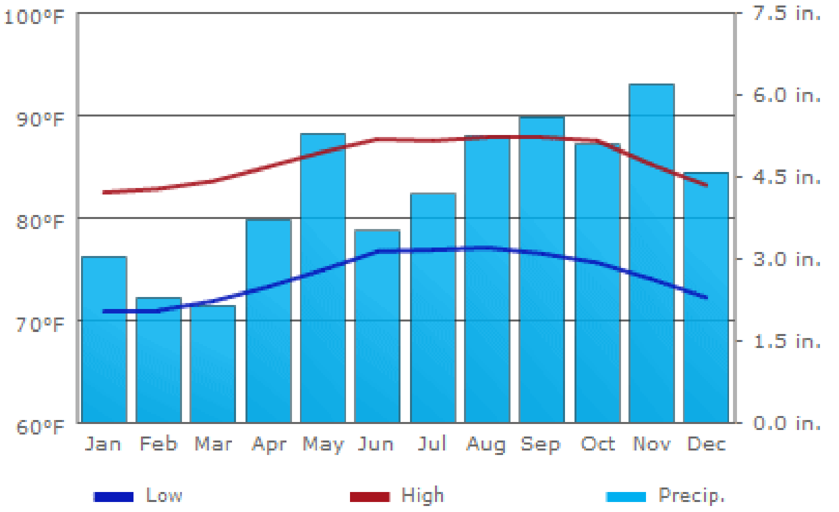
Modeling *Aedes aegypti* and Dengue Virus Ecology



Simulating Dengue Fever in San Juan, PR

- Vector population are not always reliable measures of transmission risk
  - Added pathogen and human transmission component to the model
- *Aedes aegypti* mosquitoes
  - Urban, container breeding
  - Live in tropical habitats
  - Anthropophilic
- San Juan, PR
  - Tropical climate
  - Seasonal precipitation
  - Endemic dengue
  - Seasonal cycles of transmission

http://www.interet-general.info/IMG/Aedes-Aegypti-2.jpg

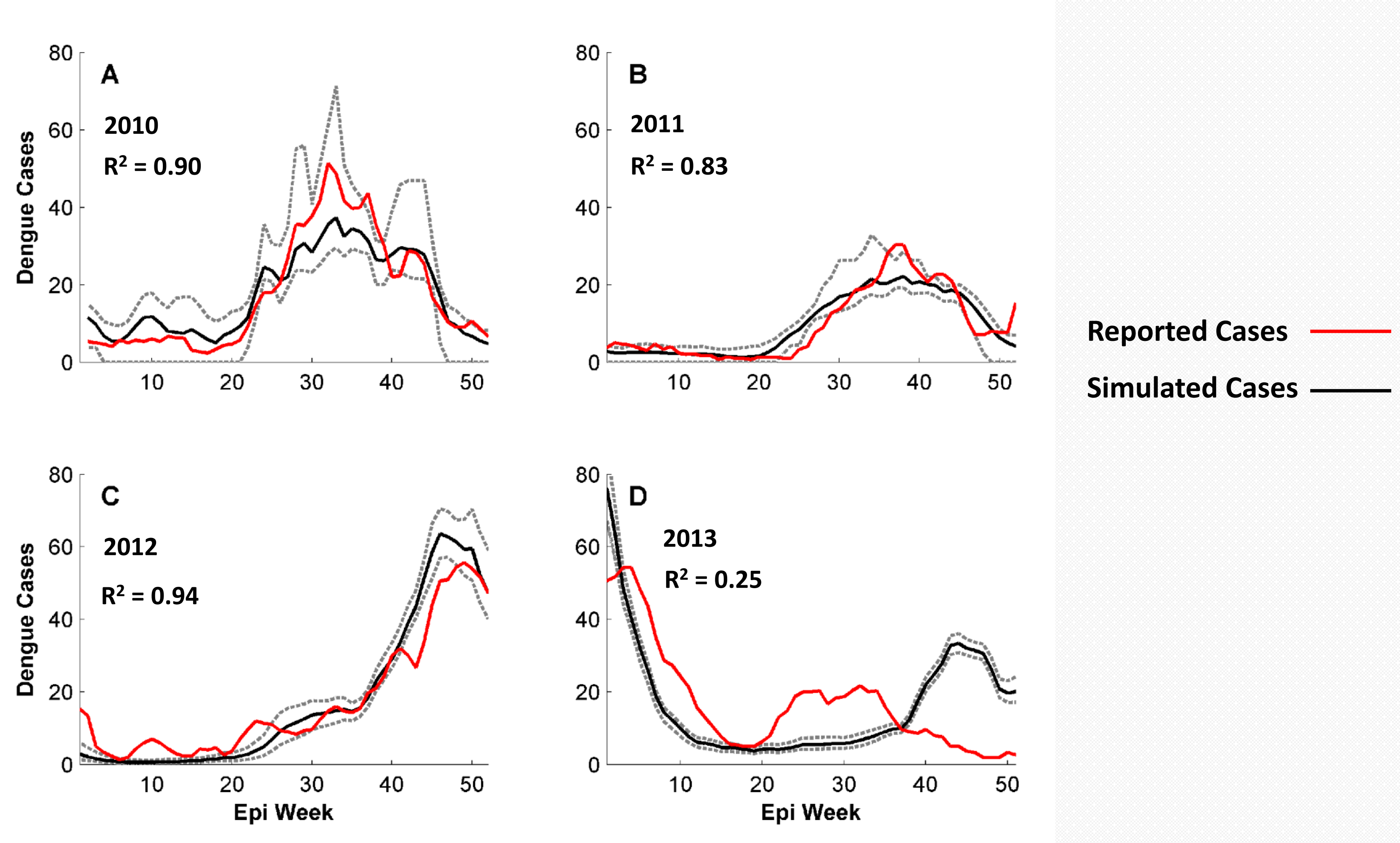


usclimatedata.com

Data and Methods

- Study Area
  - San Juan Municipality, Puerto Rico
- Meteorological and Health Data
  - Daily maximum and minimum temperatures and total precipitation for San Juan, PR
  - Weekly clinically diagnosed dengue case counts for 2010-2013 from CDC for San Juan Municipality, PR
- Model
  - Parameterized for *Aedes aegypti* mosquitoes
  - Daily time step
  - Run over time period 2009-2013 under varying parameters
    - 9600 runs
  - Chose best 1% of runs by comparing output to CDC reported data

Simulation Results (By Year)



Parameter Statistics

- Open containers vs. water storage
  - Climate dependence
  - Socioeconomic dependence

Proportion Uncovered Container	All	2010	2011	2012	2013
0.9	0	44	22	0	0
0.7	0	32	37	0	0
0.5	0	4	18	0	0
0.3	0	8	14	20	0
0.1	96	8	5	76	96

	2010	2011	2012	2013
Annual Precip	227.51	223.99	140.30	216.33

Conclusions: Modeling Dengue Fever in San Juan, PR

- Climate is a key regulator of dengue transmission in San Juan County, PR
  - Temperature limits viral replication during winter
  - Precipitation limits mosquito populations during spring
- Human response to weather and climate is important
  - Permanent water sources during dry years
- Non-climatic factors are important
  - Immunity, virus genetics, public health response

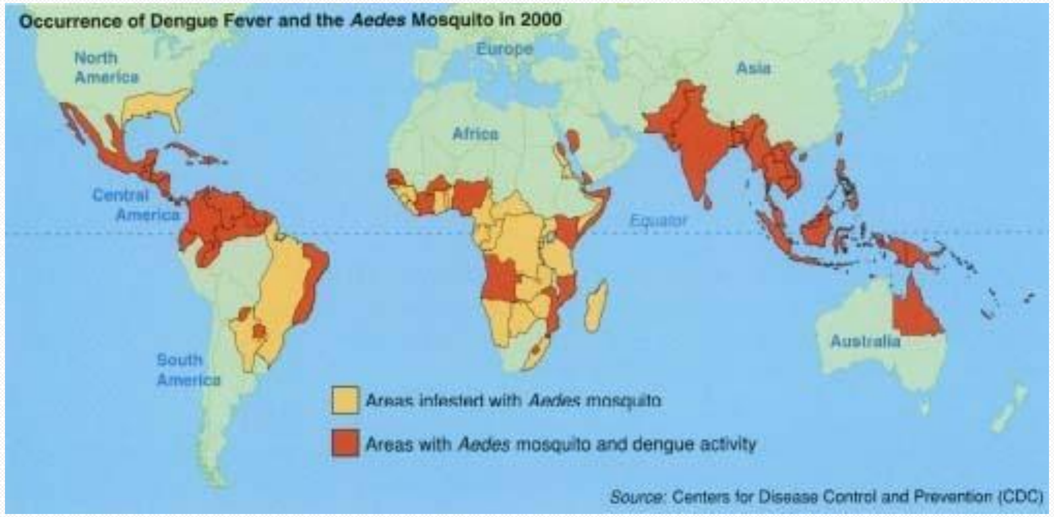
Investigating Dengue Transmission in Sonora Mexico

- Why is there little/no dengue transmission in nearby Nogales?
- Hypothesis: Climate conditions are cooler
  - Suppression of mosquito population
  - Extension of extrinsic incubation period (EIP)

- Experiments:
  - 1: Perform simulations for Hermosillo and evaluate with reported case data
  - 2: Rerun Hermosillo simulations with Nogales meteorological data
  - 3: Rerun experiment 2 with 1°C warming

Modeling Dengue Fever in Hermosillo, MX

- Study area
  - Hermosillo, Mexico
  - Arid climate, summer monsoon
- Meteorological/Dengue case data
  - Daily maximum and minimum temperatures (NLDAS)
  - Daily precipitation (TRMM, NLDAS)
  - Weekly suspected dengue cases for Hermosillo, MX 2006-2011
- Model
  - Parameterized for *Aedes aegypti*
  - Run from 2005-2011 (500 simulations)
  - Best 3% of runs chosen by comparison with suspected case data (r^2)

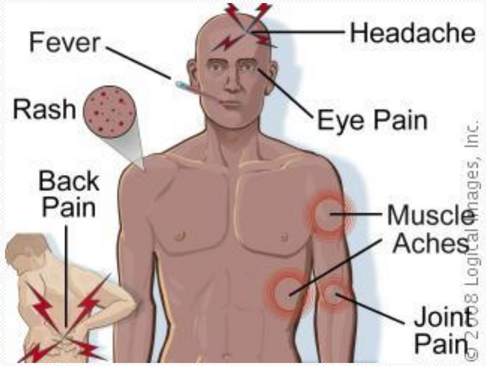


Model Parameter Estimation

- Containers
  - Based on household surveys (Hermosillo)
  - Human managed and open containers
  - Used mean values and +/- 25% and 50%

Mosquitoeater.com

beingalison.com

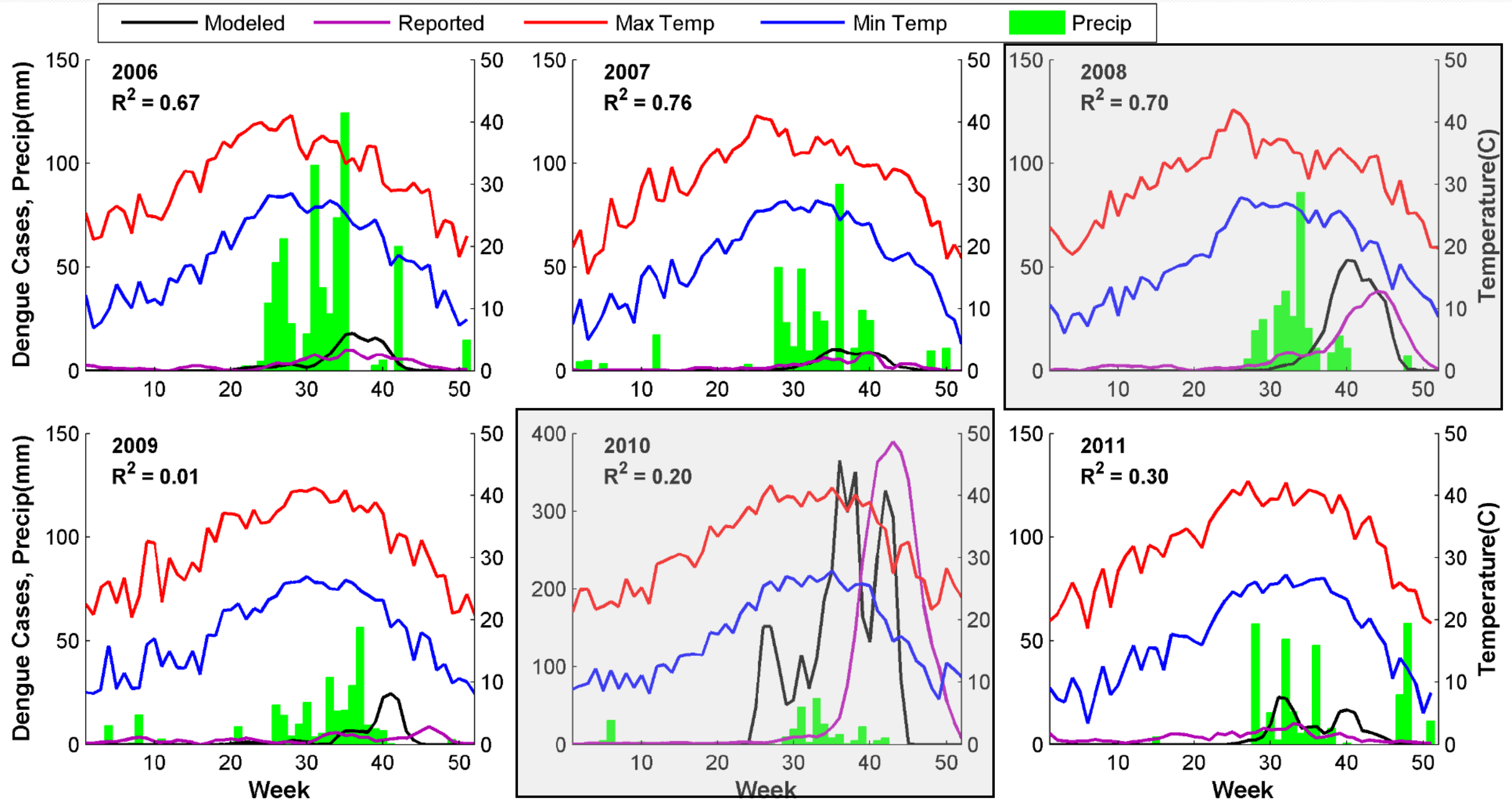


- Minimum infectious rate
  - Minimum amount of infectious humans
  - Maintains virus within the population
  - Based on case data and previous study in San Juan, PR

- Maximum larval density
  - Used to calculate density-dependent mortality
  - Based on observations, literature, and previous study in San Juan, PR

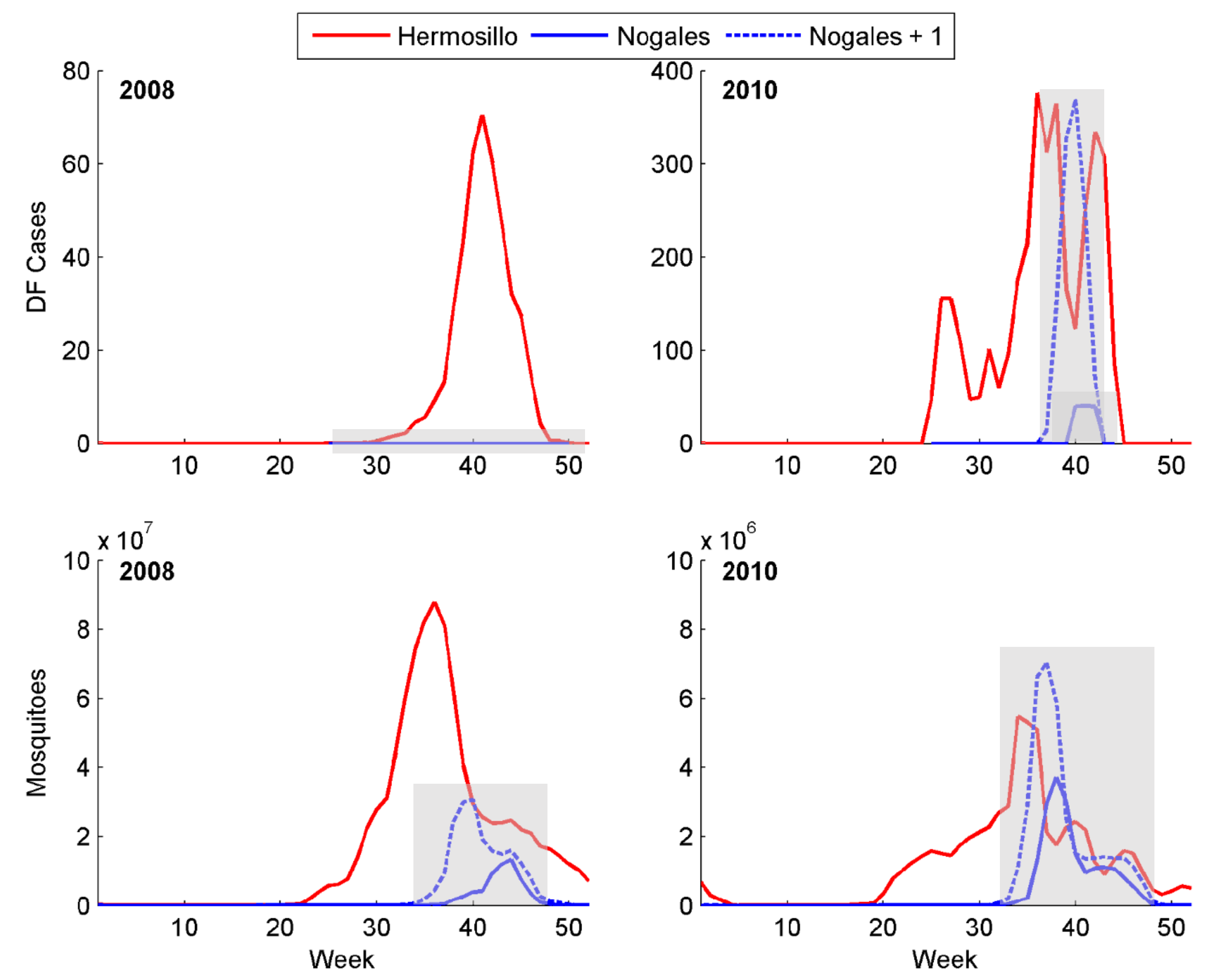
answers.yahoo.com

Climate, Dengue, Parameters: Hermosillo



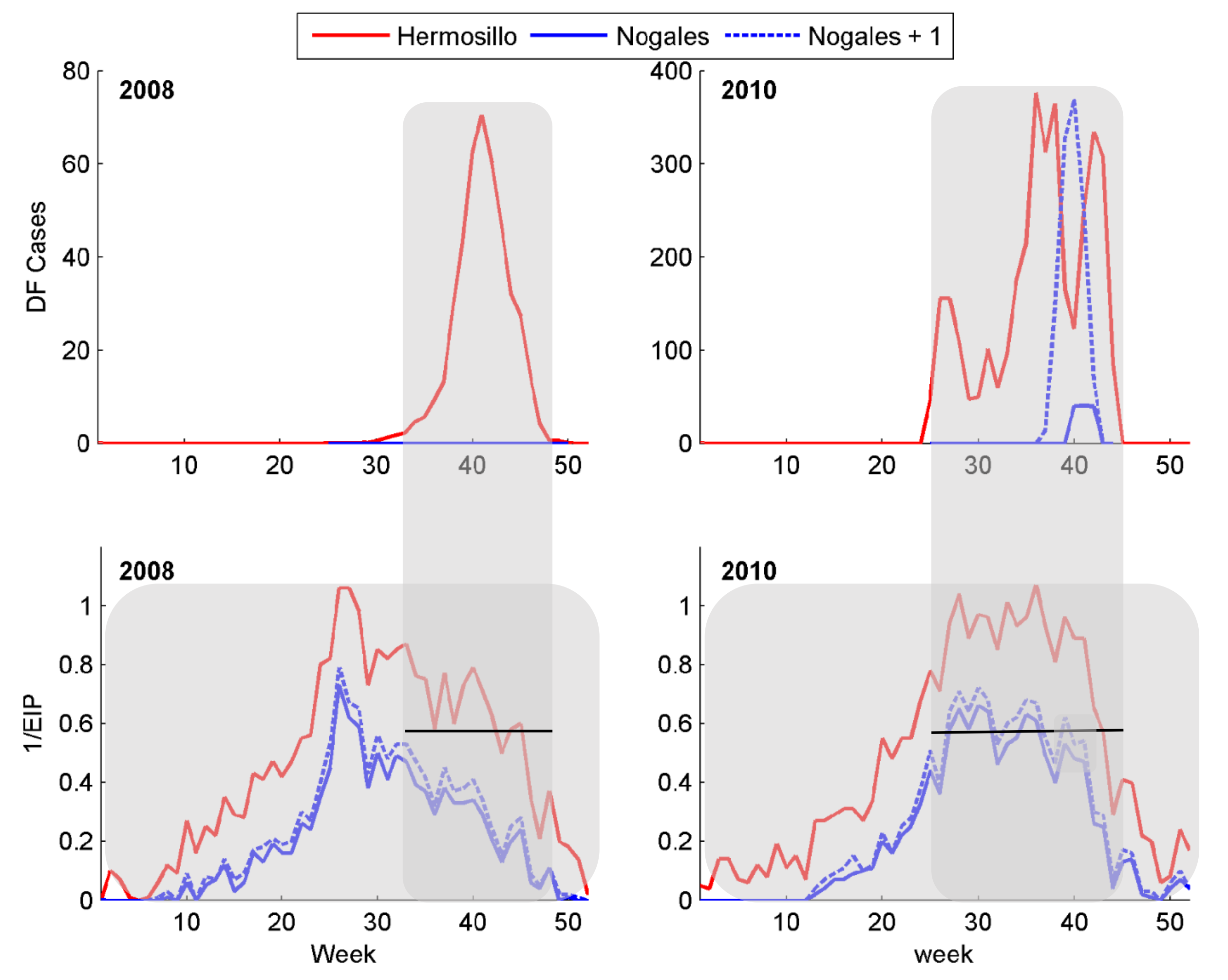
- 2008 and 2010 are largest dengue years
- Generally epidemics follow monsoon rains
- Precipitation magnitude has little influence on dengue magnitude
- Introduction from nearby areas is likely important

Hermosillo/Nogales Comparison: Mosquitoes



- Little/no dengue is simulated under Nogales meteorological conditions
- With warming, there is a modest mosquito population increase in 2008
  - No dengue
- Warming increases the mosquito considerably population in 2010
  - Results in increased virus transmission

Hermosillo/Nogales Comparison: EIP



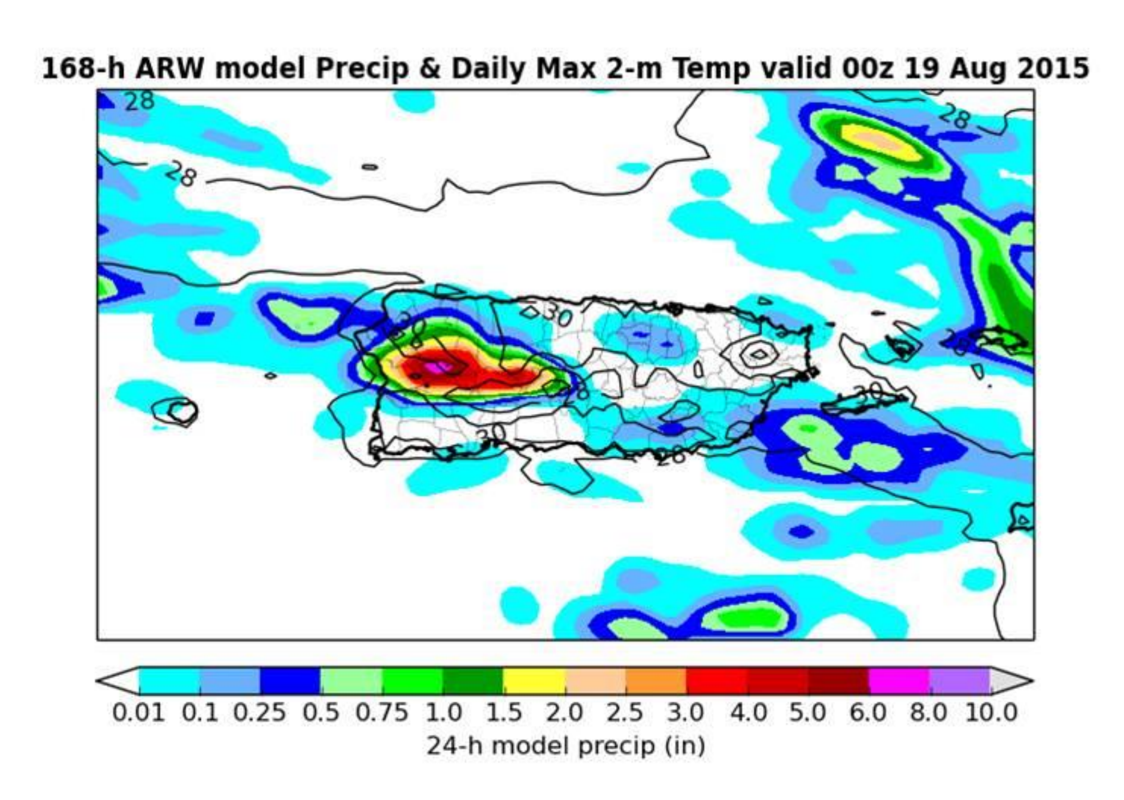
- EIP is considerably longer under Nogales conditions
- Under Nogales conditions, the EIP is longer during the transmission season in 2008
  - Prevents completion of EIP during mosquito lifetime
- EIP shortened under 1°C warming conditions
  - Especially during transmission season

Conclusions

- Dengue epidemics follows monsoon rains
  - Timing is consistent, however, the magnitude is not well correlated
- Climate is an important regulator of dengue transmission in Nogales
  - Affects mosquito population dynamics and the virus incubation period
  - Year to year variability is important
- Dengue transmission dynamics in northern Mexico may affect dengue risk in the United States
  - Travel, climate change
  - Recent dengue epidemic in Nogales

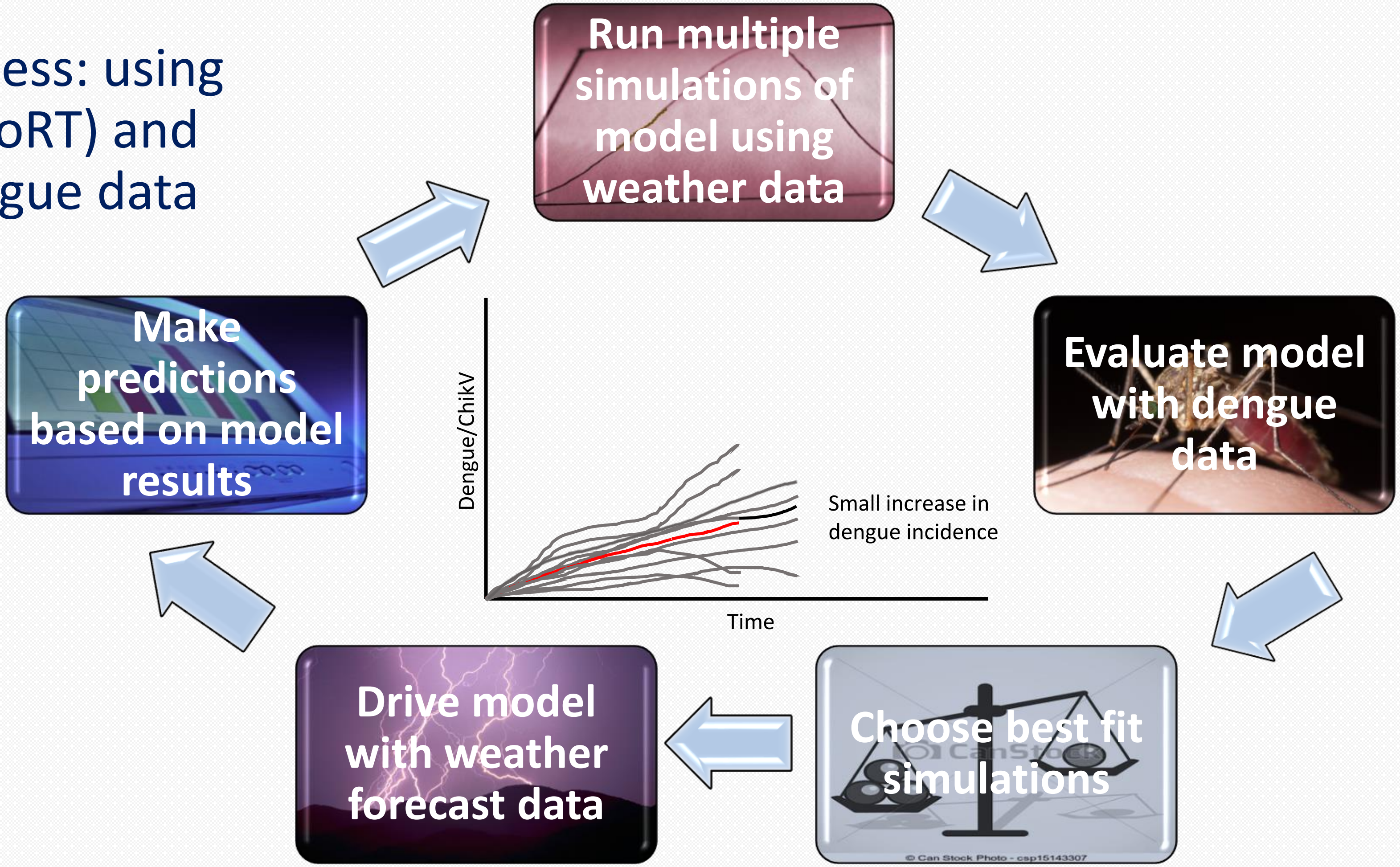
Forecasting Dengue in San Juan, PR

- Produce weekly forecasts of dengue incidence using weather forecasts
  - Allow public health workers to allocate appropriate resources for disease treatment and prevention
- Meteorological data
  - Real-time numerical weather prediction (NWP) model forecasts
  - Daily min + max temp, total precipitation
- Dengue case data
  - Puerto Rico Department of Health
  - Updated weekly



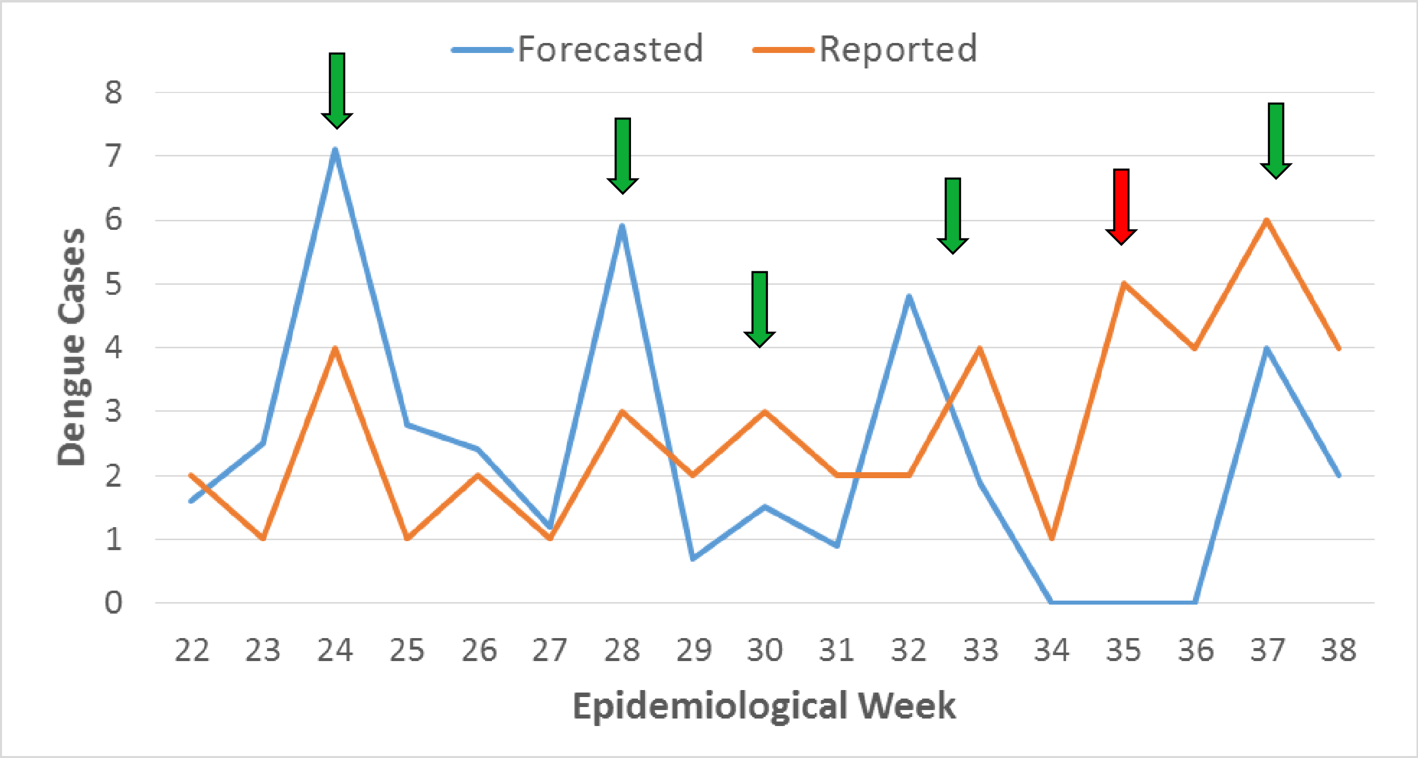
Creating and Operational Model

- Iterative weekly process: using weather forecast (SPoRT) and weekly reported dengue data



Forecast Evaluation

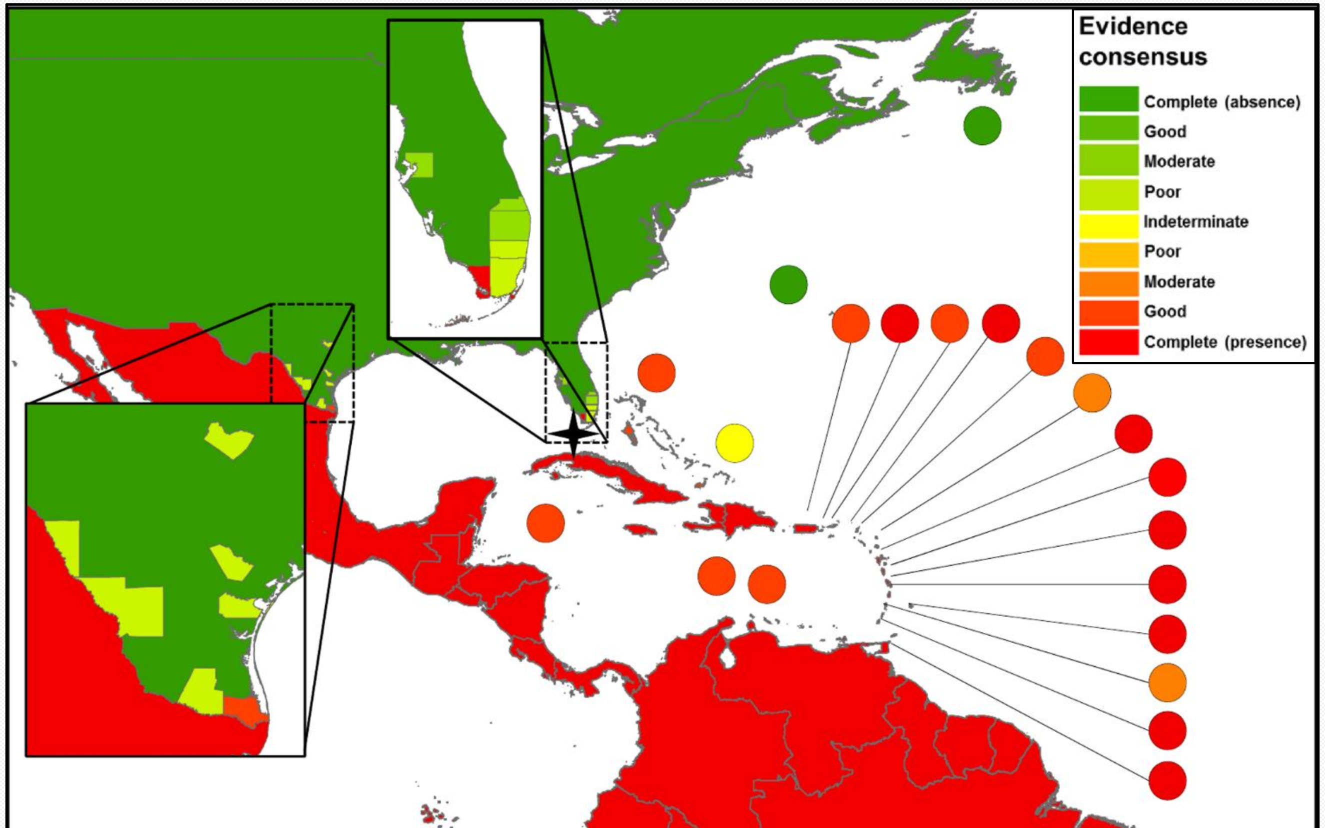
- Results are difficult to evaluate because of anomalously low dengue transmission due to El Nino caused drought



- Most spikes in cases are predicted
- However, not all of them
  - Algorithm has difficulty recovering from zero

Climate Change and Expanding Dengue Risk

- Dengue outbreaks in the US were common in 19th and early 20th century
  - Mostly around port cities
  - Improved public health measures largely eradicated the disease
- Recent transmission in the US
  - Along the Texas-Mexico boarder
  - Southern Florida (2009 – Pres)



Modified from Brady et al. 2010 in PLoS NTD

Modeling Dengue Risk under Projected Climate Conditions in the US

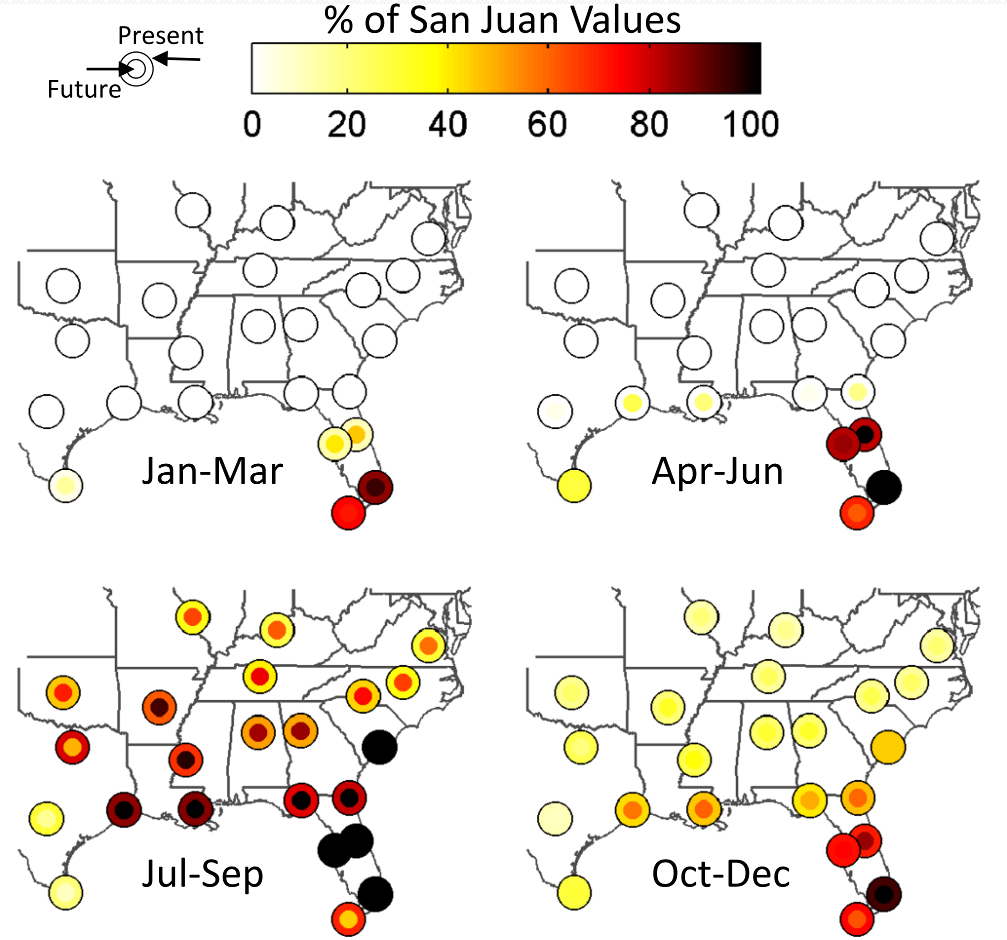
- Simulate *Aedes aegypti* populations and dengue transmission in 32 locations in the southern US
  - Use parameter values from San Juan, PR
  - Drive model with current and projected future meteorological data
    - Meteorological data produced using a weather generator trained with data from the National Climatic Data Center
    - Projected change in temperature and precipitation from the 15 gloabl climate models run using the SRA1B scenario from IPCC AR4 report
- Simulated mosquito populations and cases are compared to San Juan, PR
  - Dengue is endemic in San Juan
  - Could not parameterize the model for US locations
  - Isolate the effects of climate / climate change

Change in Aedes aegypti Population Dynamics

- *Ae. aegypti* populations increase under projected climate conditions

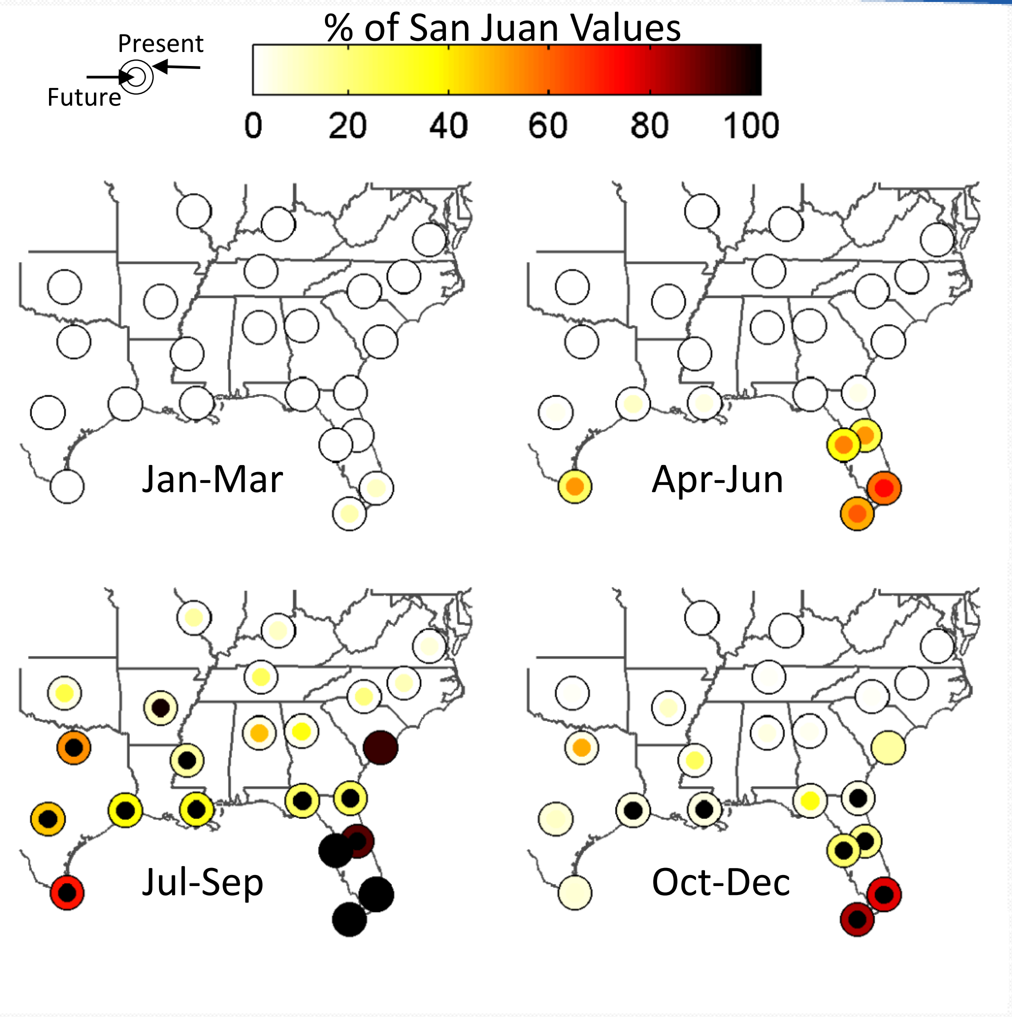
- Populations near San Juan levels during summer

- Winter populations low excepts in summer Florida



Change in Dengue Transmission Dynamics

- Dengue range is more limited than that of *Ae. aegypti*
- Future summer and fall case magnitudes match those of San Juan
- Winter transmission is almost non-existent



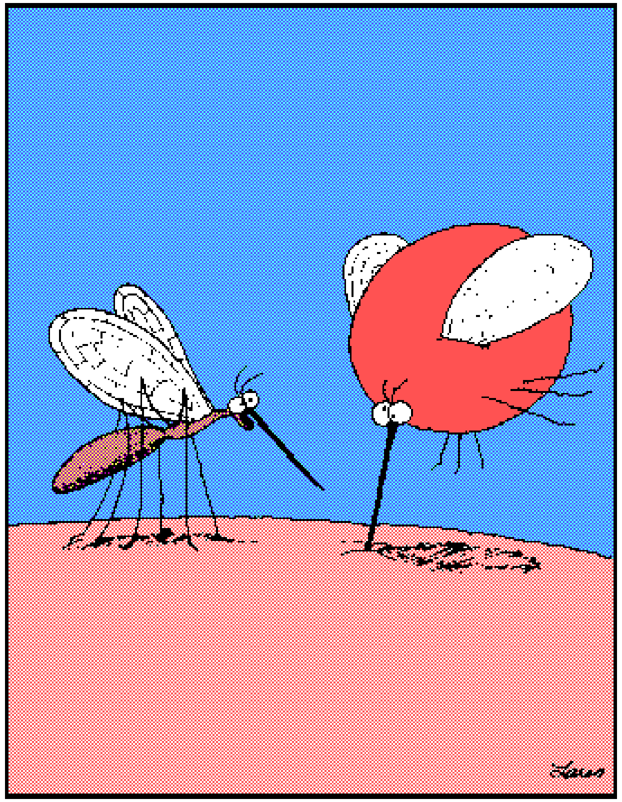
Conclusions

- The future risk of dengue transmission is not synonymous with that of *Ae. aegypti*
- Most locations in the southern US can support dengue transmission but only for a short period during the year
    - Creates risk of small, local outbreaks
- Winter temperatures are likely a major barrier for sustained dengue transmission in the continental US

Overall Conclusions and Future Work

- Understanding climate and environmental effects on infectious disease ecology provides opportunities to simulate, investigate, and predict transmission dynamics
- However, natural and human systems are complex and coupled requiring interdisciplinary efforts to truly understand
- Future research must identify methods to transition research to better public health practice
  - Incorporate socio-economic and demographic variables into models
  - Creation of seasonal forecasts to help preparedness

Thank You for Your Attention!



"Pull out, Betty! Pull out! ... You've hit an artery!"