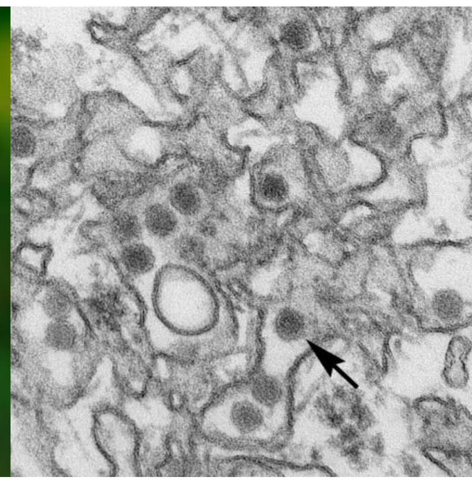
National Center for Emerging and Zoonotic Infectious Diseases

Climate Change as a Driver for Vector-Borne Disease Emergence


C. Ben Beard, MS, Ph.D.

Associate Director for Climate Change
National Center for Emerging and Zoonotic Infectious Diseases

Chief, Bacterial Diseases Branch
Division of Vector-Borne Diseases, NCEZID, CDC

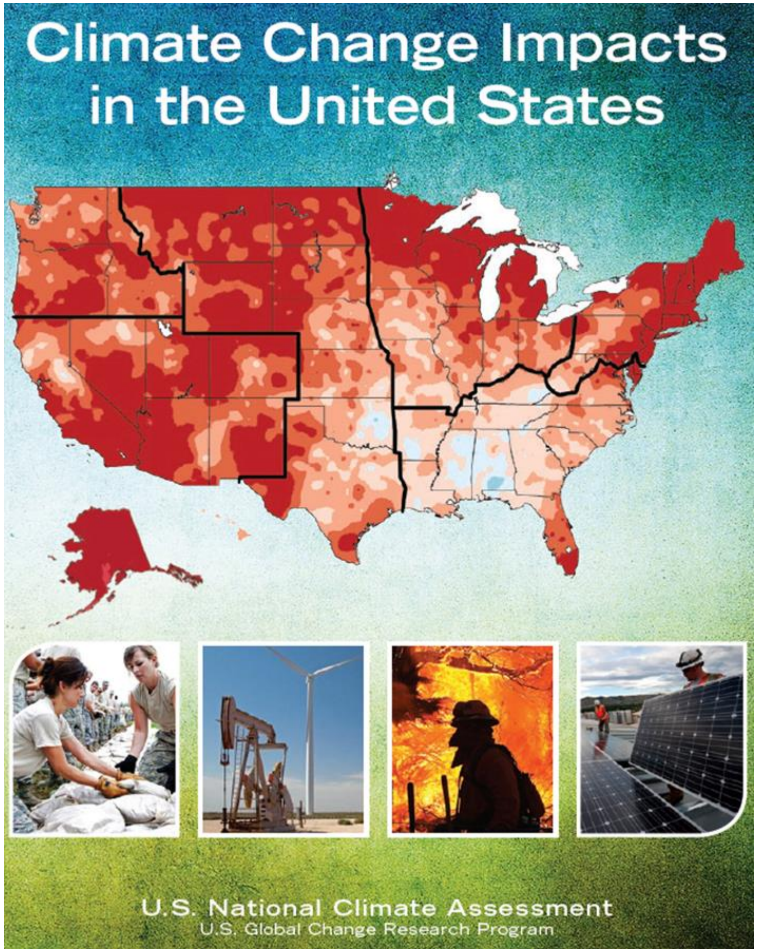
Outline

- Climate change observations and projections relevant to disease emergence
- Climate-sensitive infectious diseases – incidence and trends
- Climate change and infectious diseases – case studies
- Developing a public health framework

Climate change observations and projections relevant to disease emergence

3rd National Climate Assessment

- Published 2014
- Summarizes impacts for many sectors
  - Public health
  - Energy
  - Water
  - Transportation
  - Agriculture
- Represents 3-year effort
- Includes work of 240 authors in 30 chapters



Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program

3rd National Climate Assessment Key Findings – Temperature and Precipitation Impacts

- Temperature increases
  - Average US temperature has increased by about 1.5°F (0.8°C) since 1895
  - Temperatures are projected to rise between 2° to 11.5°F (1.1° to 6.4°C) more by 2100
  - Shorter periods of frost since the 1980s
- Precipitation changes
  - Heavy downpours have increased in most regions of the United States
  - More precipitation as rain; less as snow
  - In general, wet areas will get wetter, dry areas will get drier

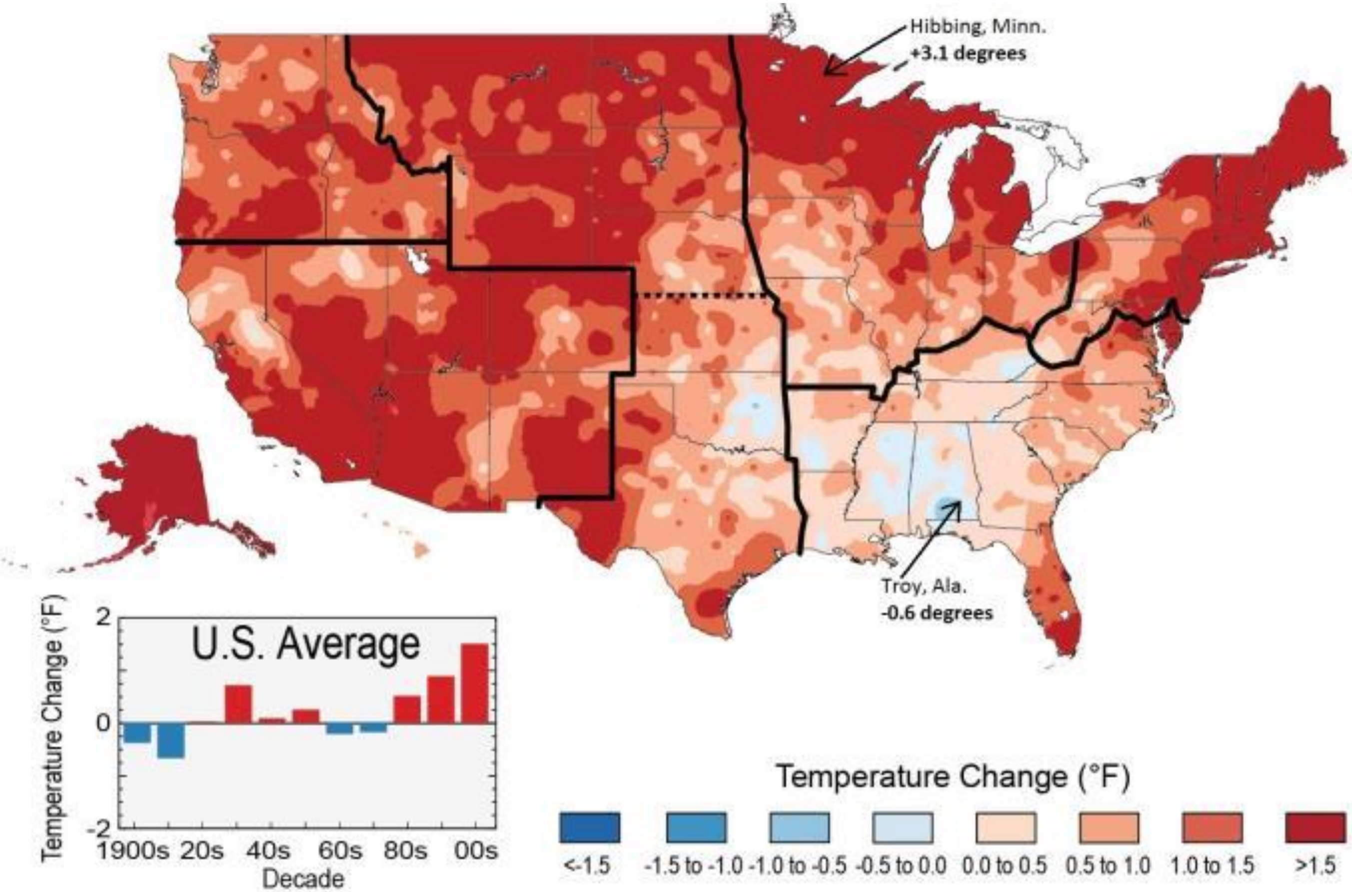
Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program

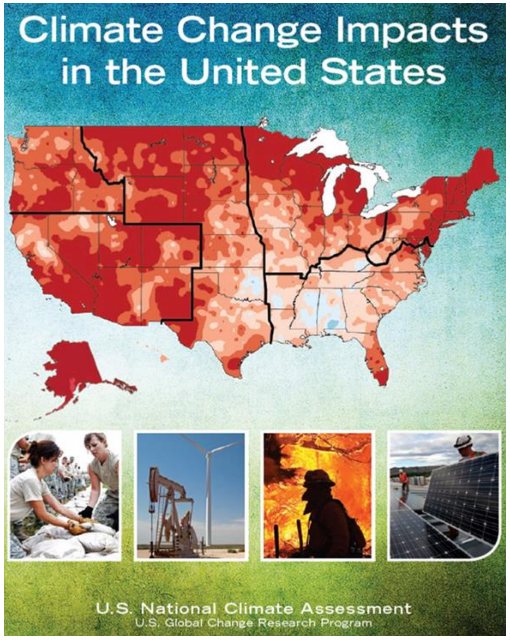
3rd National Climate Assessment Key Findings – Extreme Weather and Ocean Impacts

- Increases in extreme weather events
  - Heat waves, floods, and droughts have become more frequent and intense
  - Number of Category 4 and 5 hurricanes in the North Atlantic has increased since early 1980s
- Impacts on oceans
  - Sea level has risen about 8 inches since 1880
  - Sea level is projected to rise another 1 to 4 feet by 2100
  - Ocean acidity has increased 26% since the start of the industrial era as a result of the ocean's carbon dioxide absorption

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program

Climate Change Impacts in the U.S.





1991 – 2012 average temperature compared with 1901 - 1960 average

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program

Climate Change Impacts in the U.S.

Observed Increase in Frost-Free Season Length

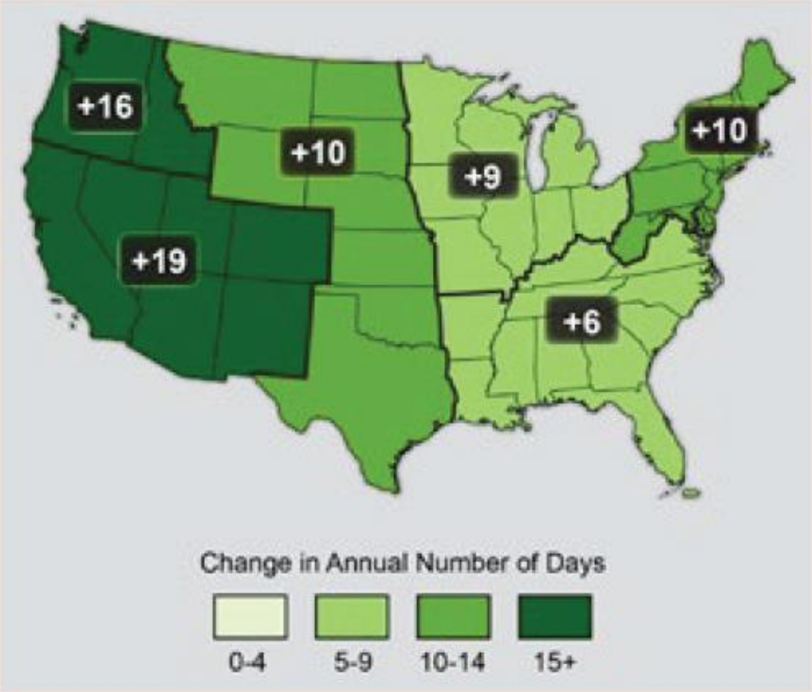
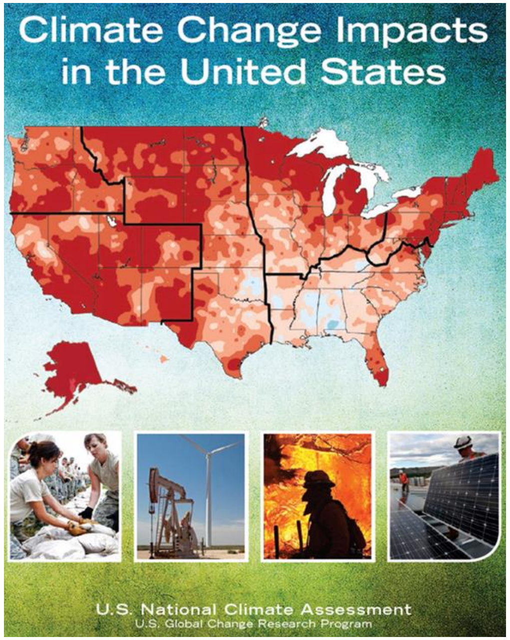
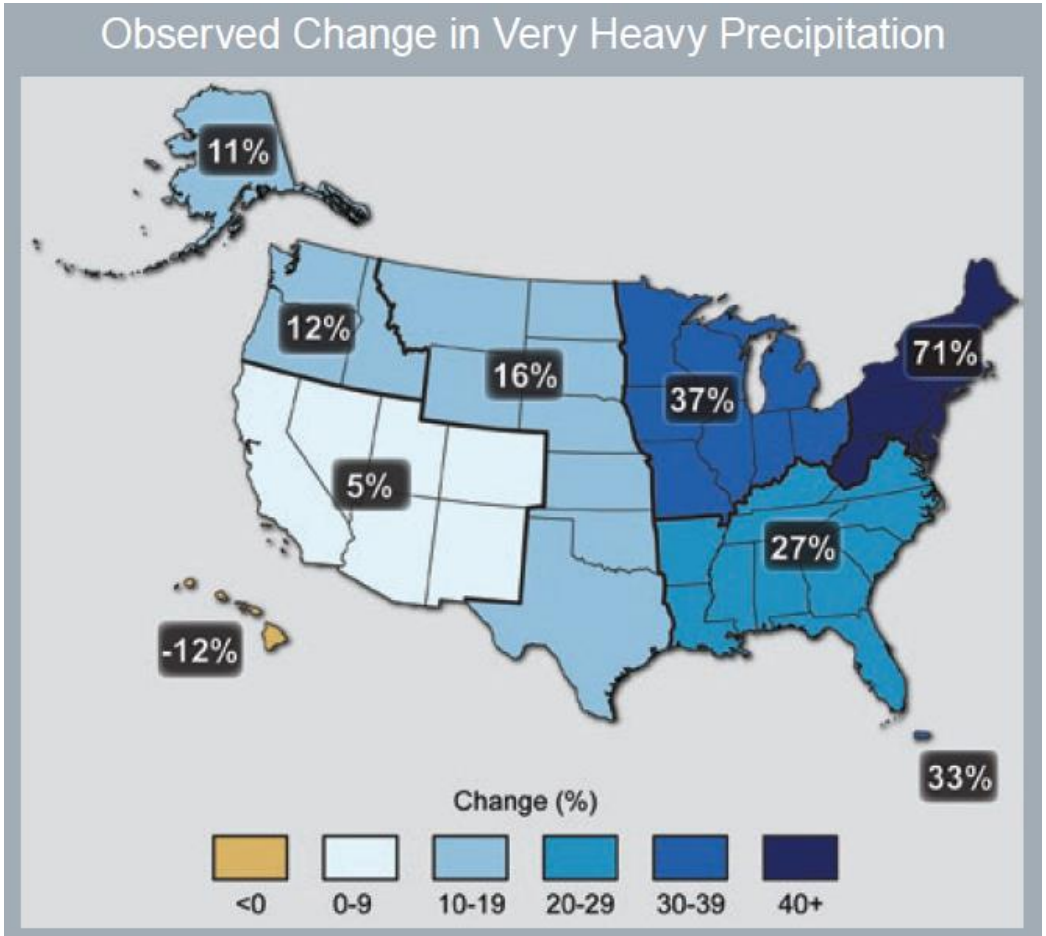


Figure 2.10. The frost-free season length, defined as the period between the last occurrence of 32°F in the spring and the first occurrence of 32°F in the fall, has increased in each U.S. region during 1991-2012 relative to 1901-1960. Increases in frost-free season length correspond to similar increases in growing season length. (Figure source: NOAA NCDC / CICS-NC).

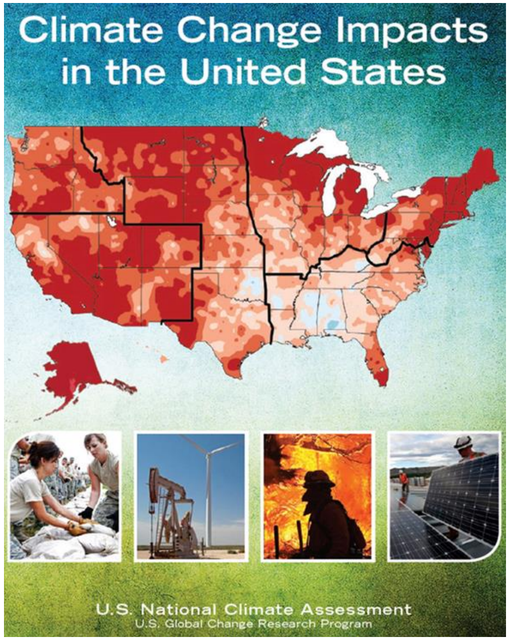


Source: NCA3; NOAA NCDC/CICS-NC

Climate Change Impacts in the U.S.



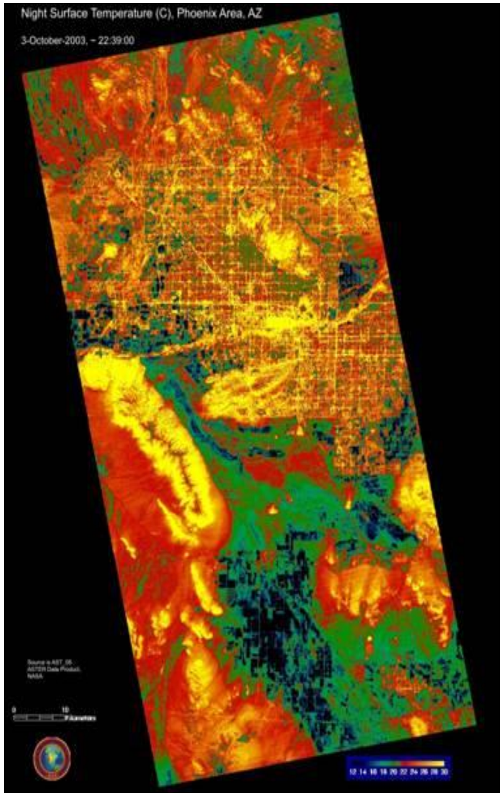
Percent changes in the amount of precipitation falling in very heavy events (the heaviest 1%) from 1958 to 2012 for each region. There is a clear national trend toward a greater amount of precipitation being concentrated in very heavy events, particularly in the Northeast and Midwest. (Figure source: updated from Karl et al. 2009[c]).



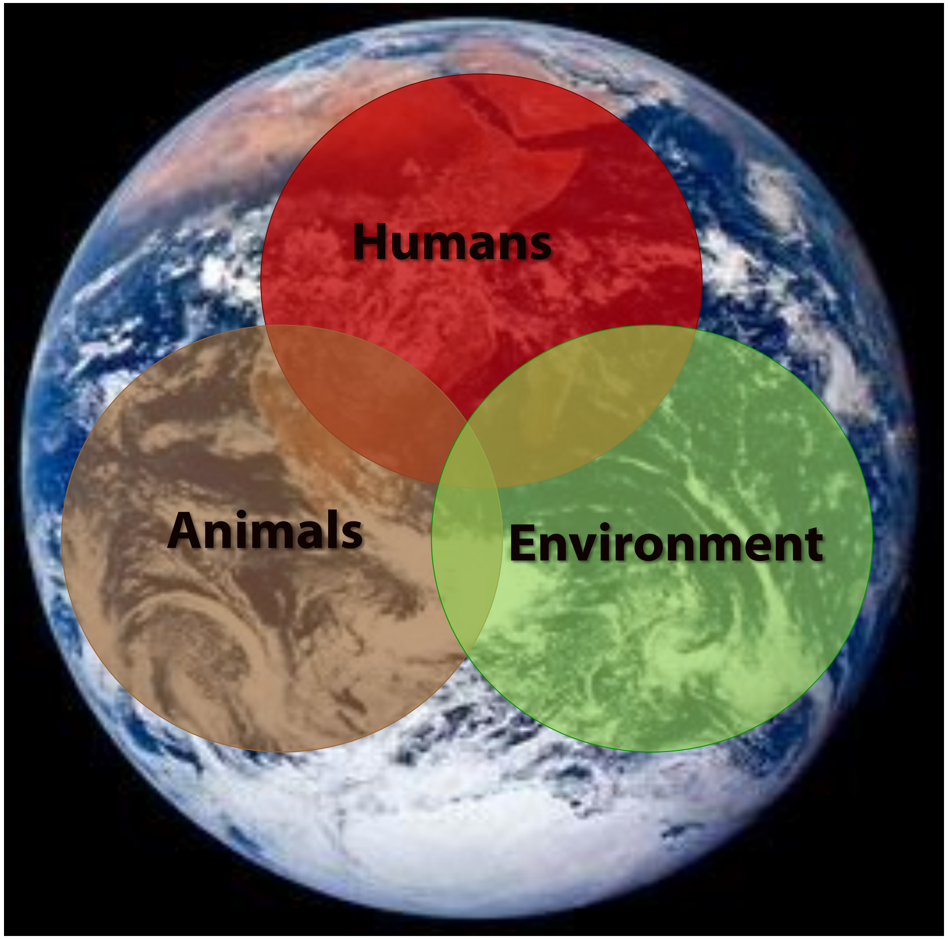
Source: NCA3; Karl et al 2009

Climate Change – Anticipated Trends…

- Longer and warmer summers
- Shorter and milder winters
- Increased frequency of severe and unpredictable weather events (e.g. storms, heat waves, droughts)
- Regional variations



Climate Change and Emerging Infectious Diseases through a *One Health* Lens



Changes in climate lead to changes in the environment, which result in changes in the incidence and distribution of diseases that have strong environmental linkages

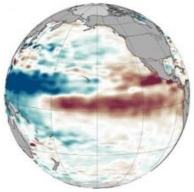
Climate, Weather, and Infectious Diseases: The Big Picture

- Climatic variables (temperature and rainfall) affect disease transmission by impacting the replication, interaction, and survival of disease agents in animals, disease vectors, and the environment
- Climatic perturbations such as severe storms, droughts, and ENSO affect disease occurrence patterns and drive disease outbreaks
  - ENSO (El Niño Southern Oscillation) describes both warm (El Niño) and cool (La Niña) ocean-atmosphere events that begin in the tropical Pacific Ocean

Luber, G., et al. 2014: Ch. 9: Human Health. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 220-256

Gage, K. L., T. R. Burkot, R. J. Eisen, and E. B. Hayes. American Journal of Preventive Medicine, 35, 436-450

Climate Change and El Niño

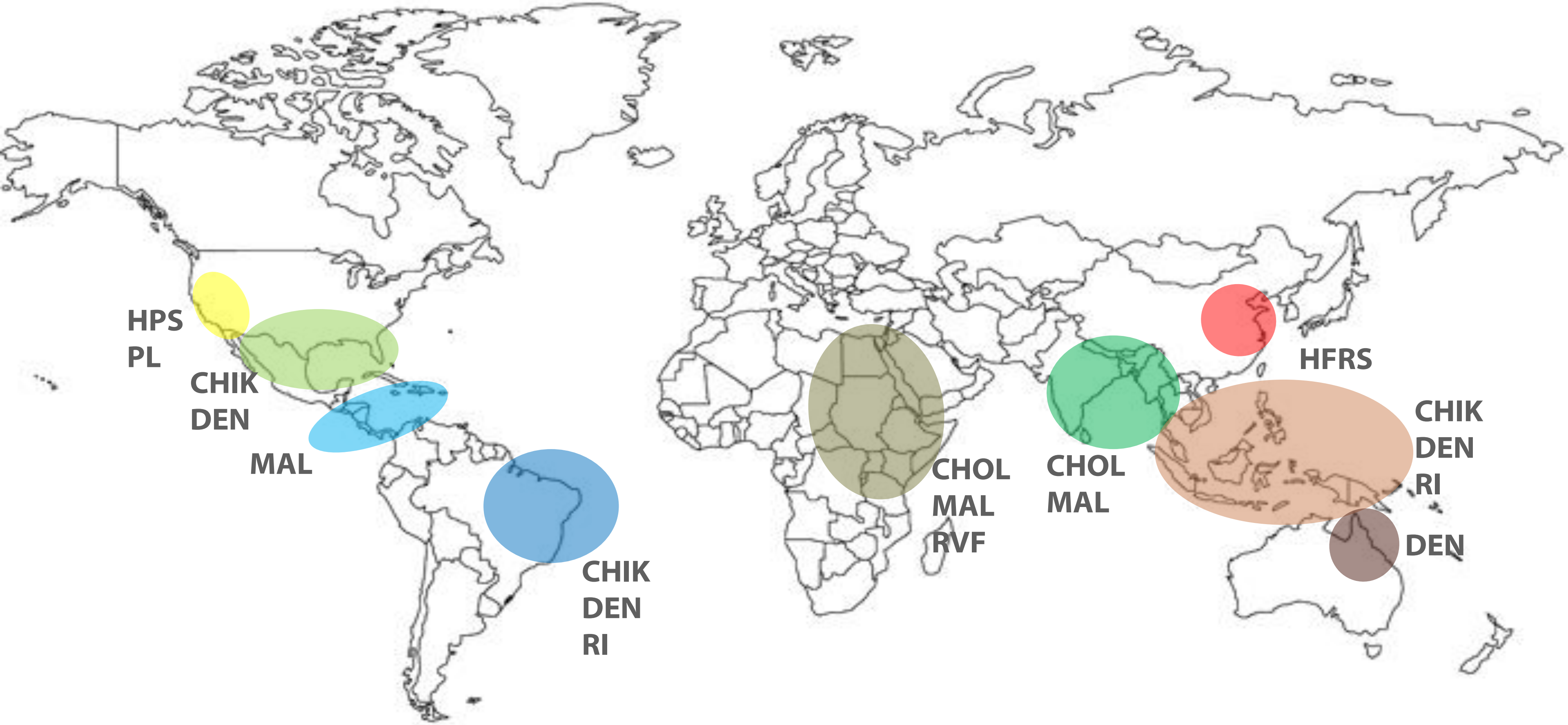


- El Niño events lead to changes in precipitation and temperature patterns across many regions of the world, including the U.S.
- Effects in the U.S. are typically seen in the cooler months of the year and are characterized by cooler and wetter seasonal weather.
- El Niño events are not caused by climate change, nor are they expected to occur at greater frequencies, but climate change may lead to greater El Niño intensity.
- According to the NOAA Climate Prediction Center, the recent El Niño event is one of the strongest in recorded history.
- El Niño events have been linked to increases in vector-borne diseases such as Rift Valley Fever in Kenya, due to increased rainfall and the subsequent impact on mosquito populations

https://www.climate.gov/enso

Climate, Weather, and Infectious Diseases:

Potential Elevated Risks Associated with ENSO



Chretien J, Anyamba A, Small J, Britch S, Sanchez, JL, Halbach AC, Tucker C, Linthicum KJ. 2015. Global Climate Anomalies and Potential Infectious Disease Risks: 2014-2015. PLOS Currents Outbreaks. 2015 Jan 26. Edition 1. doi: 10.1371/currents.outbreaks.95fbc4a8fb4695e049baabfc2fc8289f.

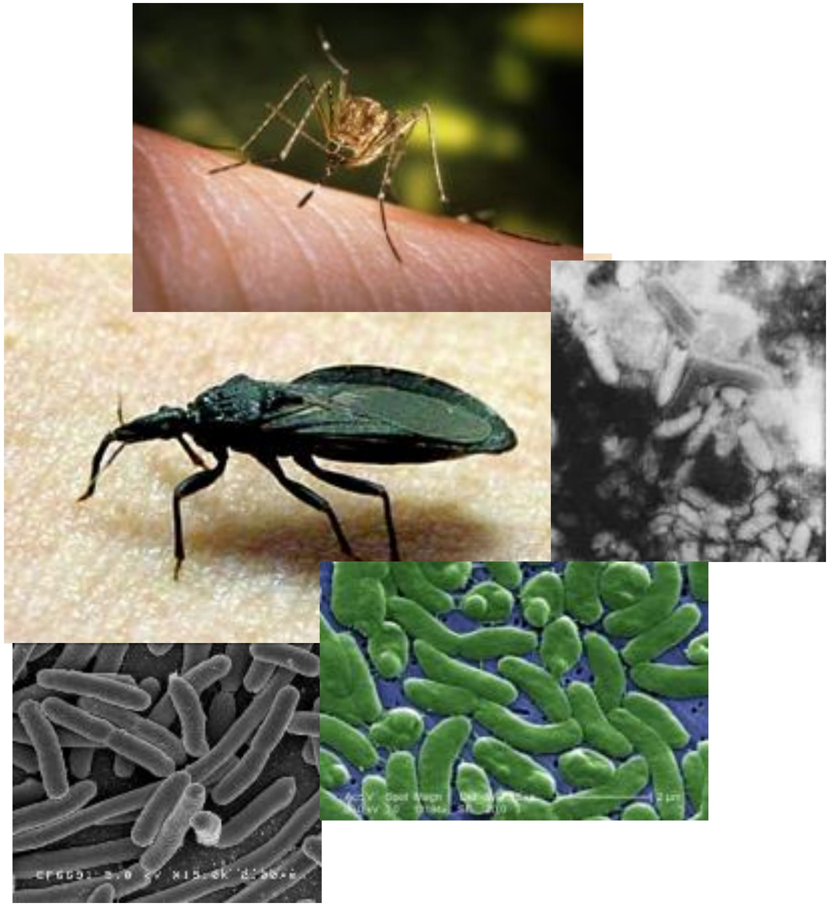
Climate-sensitive infectious diseases – incidence and trends

Types of Climate-sensitive Infectious Diseases

- Zoonotic
  - Diseases that can be spread from animals to humans
- Vector-borne
  - Diseases that are transmitted to humans through carriers (vectors) such as mosquitoes or ticks and are usually harbored in wild animals
- Waterborne
- Foodborne
- Soil and dust associated

Selected Infectious Diseases Potentially Affected by Climate Change

- Vector-borne and Zoonotic
  - West Nile virus infection
  - Lyme disease
  - Rabies
  - Dengue
  - Rift Valley Fever
  - Chagas disease
- Environmentally-associated
  - *E. coli* O157H7 infection
  - Cholera
  - Leptospirosis
  - Vibriosis
  - Valley fever
  - Primary amoebic meningoencephalitis



Environmentally-sensitive Diseases in the U.S. – Recent Observations*

- Inter-annual trends in West Nile virus epidemics
- Autochthonous dengue, Chikungunya, and Zika transmission in Florida
- Northward expansion of Eastern Equine Encephalitis
- Valley Fever (coccidioidomycosis) emergence in the western U.S.
- *Cryptococcus gattii* emergence in the Pacific NW
- Northward expansion of Primary Amoebic Meningoencephalitis (PAM)
- Increases in the incidence and distribution Lyme and other TBDs

** Not necessarily linked to climate change*

Reported Cases of Vector-Borne Diseases in the U.S., 2014

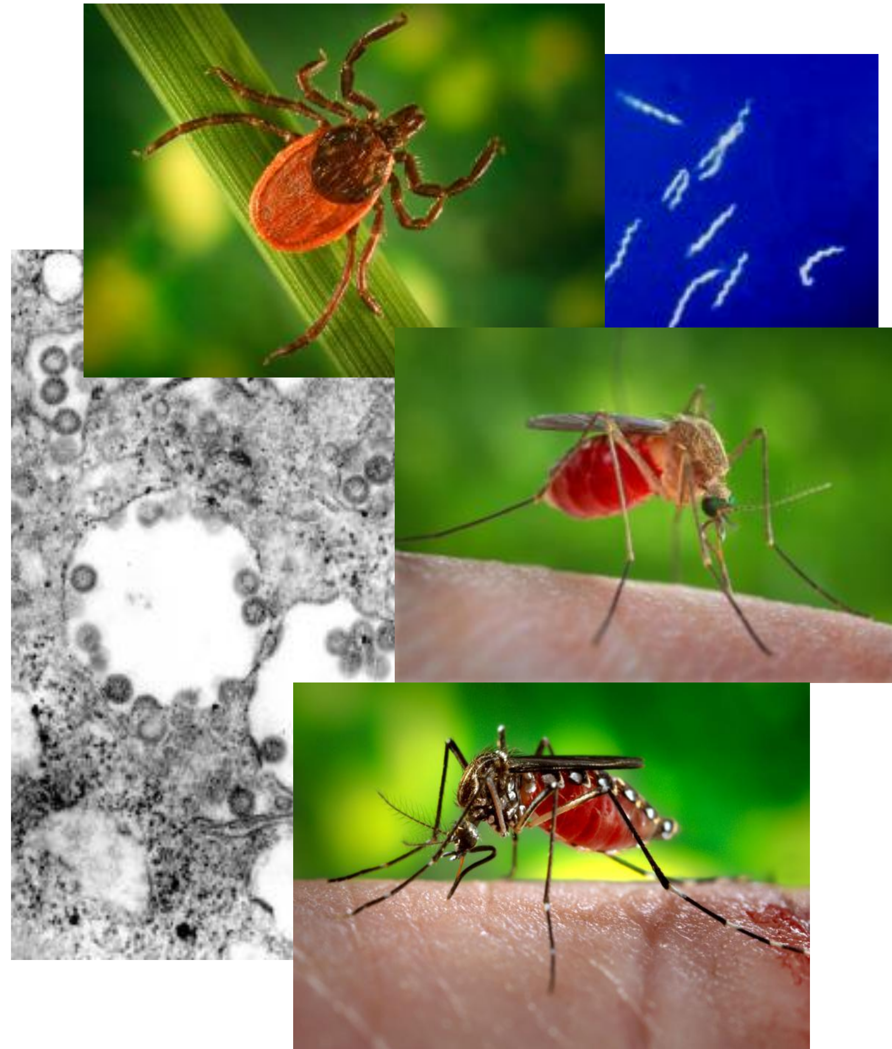
Diseases	2014 Cases	Median (range) 2004-2014
Tick-borne		
Lyme disease	33,461	30,831 (19,804 – 38,468)
Spotted Fever Rickettsioses	3,647	2,288 (1,713 – 4,470)
Anaplasmosis/ Ehrlichiosis	4,488	2,267 (875 – 4,551)
Babesiosis*	1,759	1,444 (940 – 1,792)
Tularemia	180	137 (93 – 203)
Powassan virus disease	8	7 (1-16)
Mosquito-borne		
West Nile virus infection	2,205	2,205 (712 – 5,673)
Malaria*	1,653	1,494 (1,255 – 1,773)
Dengue*	677	677 (254 – 843)
California serogroup viruses	96	80 (55 – 137)
Eastern Equine Encephalitis	8	8 (4 – 21)
St. Louis encephalitis	6	10 (1-13)
Flea-borne		
Plague	10	4 (2 – 17)

*Dengue and malaria cases are primarily imported. Babesiosis and Dengue have only been notifiable since 2011 and 2009, respectively. Median and range values encompass cases reported from 2011 to 2014 for Babesiosis and 2010 to 2014 for dengue.

Climate change and infectious diseases – case studies

Case Studies:

- Lyme Disease
- West Nile Virus Infection
- Zika Virus Disease



Case Study 1: Lyme Disease

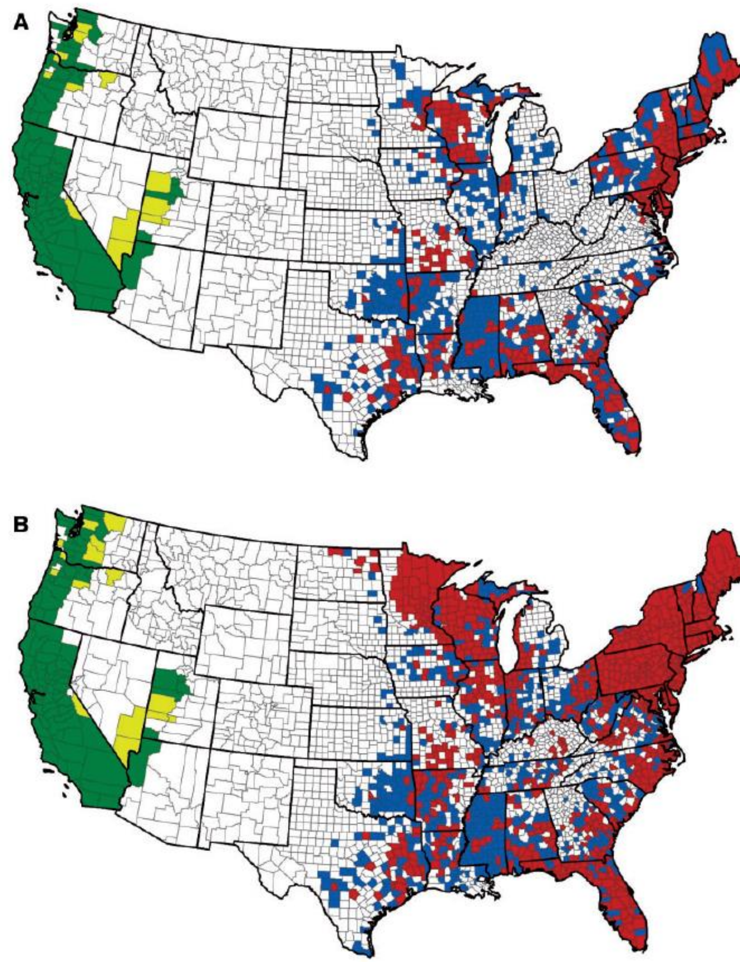
- Caused by the spirochete bacteria *Borrelia burgdorferi*
- Transmitted by *Ixodes* species ticks (Black-legged tick)
- Reservoirs for the spirochete include small mammals (field mice, squirrels, chipmunks, etc.) and birds
- Hosts for the tick include
  - Small mammals (larvae and nymphs)
  - Deer and other large mammals (adults)
- Human illness can range from a fever, fatigue, and rash to carditis, facial palsy, and arthritis later in illness

County-Scale Distribution of *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae) in the Continental United States

Rebecca J. Eisen,[1] Lars Eisen, and Charles B. Beard

Journal of Medical Entomology, 2016, 1–38
doi: 10.1093/jme/tjv237
Research article

OXFORD



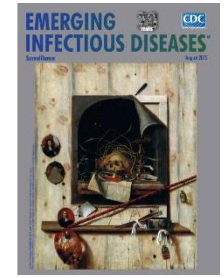
1996

2015

From 1996 – 2015…

- *I. scapularis* or *I. pacificus* now found in 49.2% of counties in 43 states
- Marks a 44.7% increase in the number of positive counties
- The number of counties where *I. scapularis* is now established has more than doubled in the last 20 years

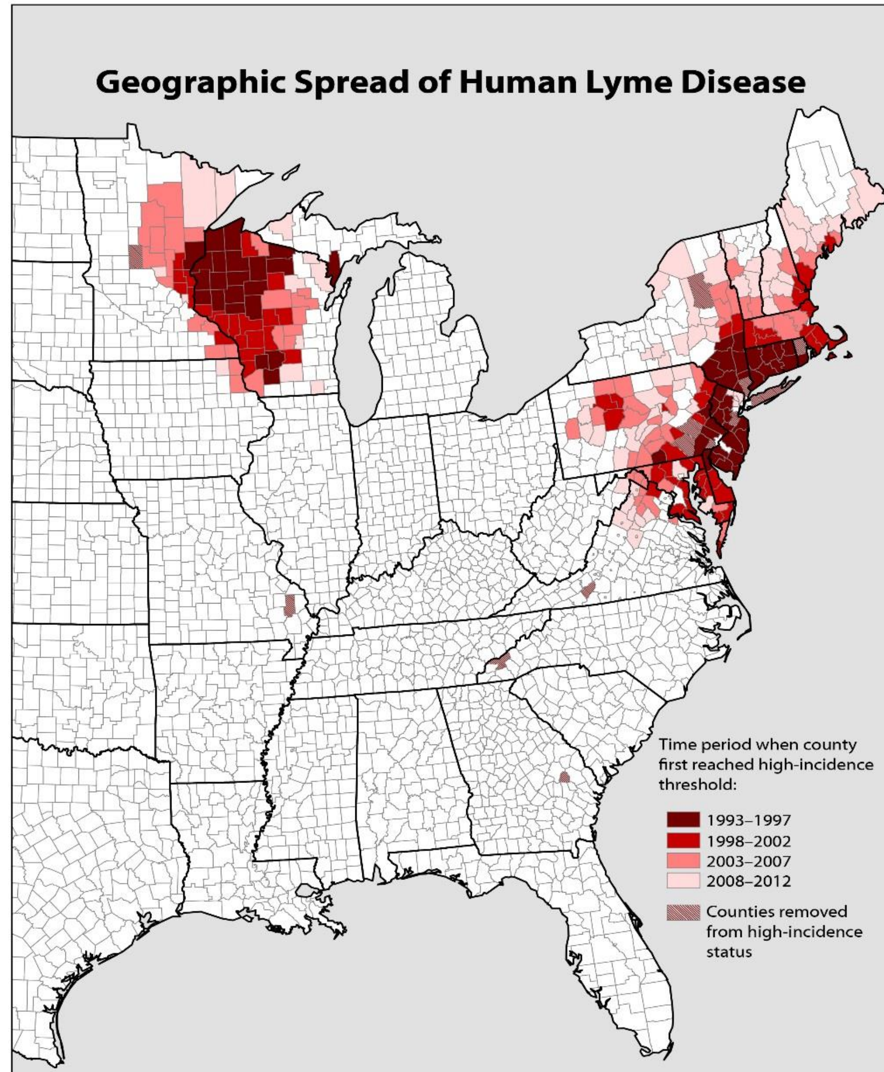
Geographic Distribution and Expansion of Human Lyme Disease, United States



Kiersten J. Kugeler, Grace M. Farley, Joseph D. Forrester, Paul S. Mead

Lyme disease occurs in specific geographic regions of the United States. We present a method for defining high-risk counties based on observed versus expected number of reported human Lyme disease cases. Applying this method to successive periods shows substantial geographic expansion of counties at high risk for Lyme disease.

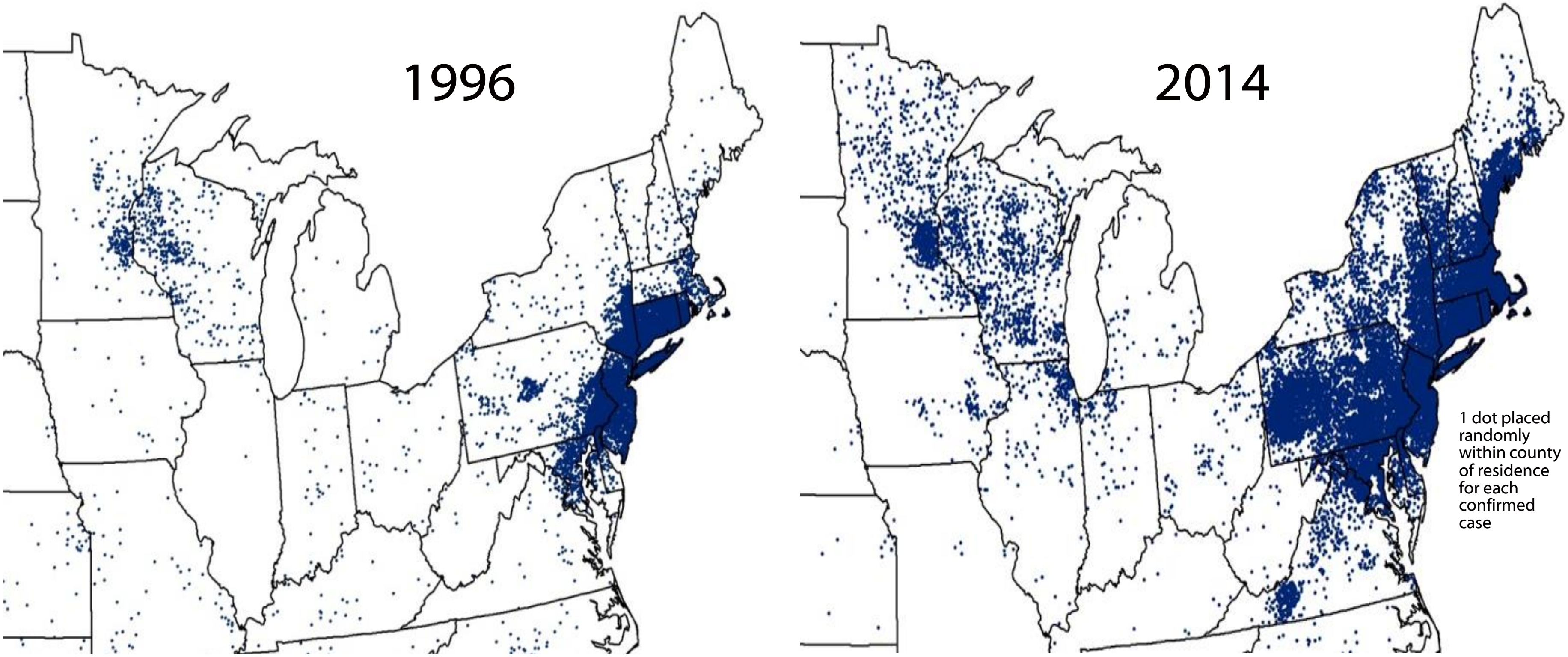
Emerging Infectious Diseases, Vol. 21, No. 8, August 2015;
DOI: http://dx.doi.org/10.3201/eid2108.141878



From 1993 – 2012…

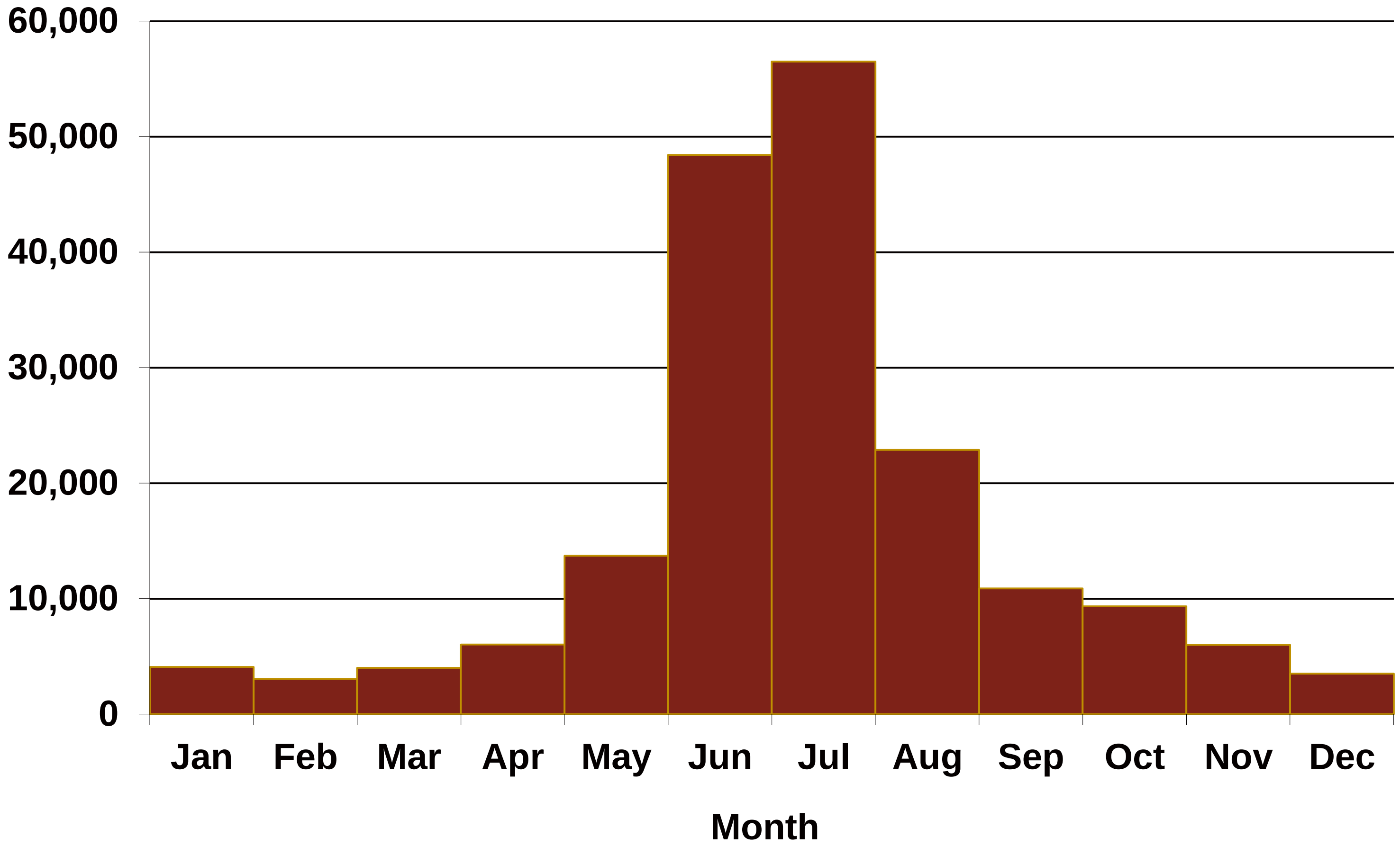
- Number of high incidence counties in the northeastern U.S. increased by >320%
- Number of high incidence counties in the north-central U.S. increased by ≈ 250%

Lyme Disease US Case Distribution: 18-year Trend



http://www.cdc.gov/lyme/stats/maps/interactiveMaps.html

Reported Lyme Disease Cases by Onset Month, United States, 15-year period



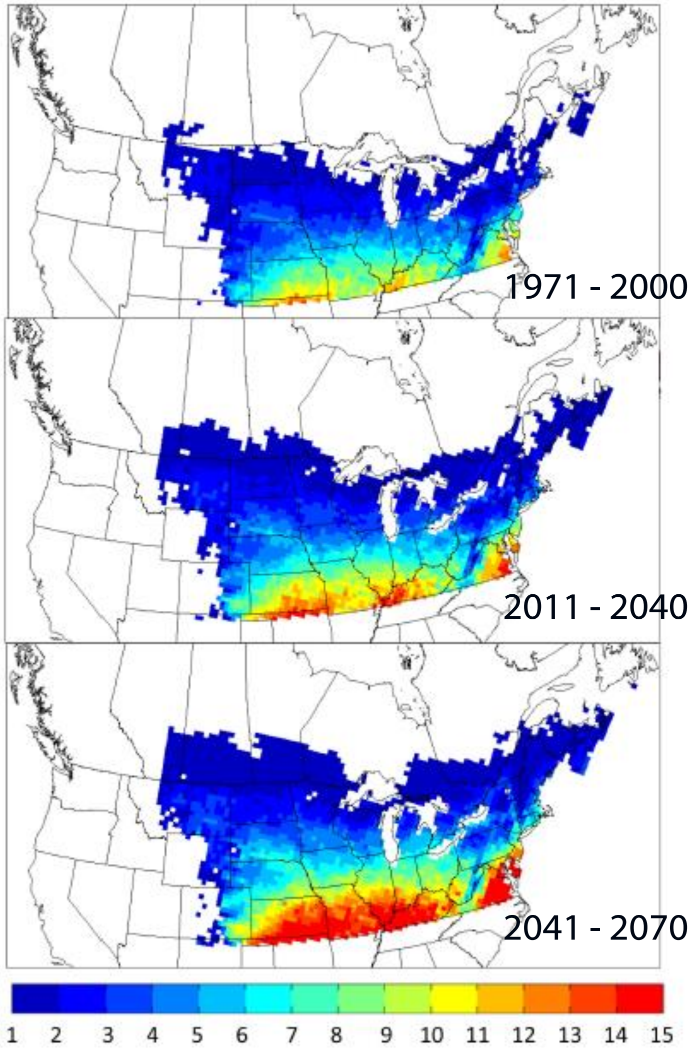
Murphree Bacon R, Kugeler KJ, Mead PS. 2008, MMWR 57:SS-10; http://www.cdc.gov/mmwr/preview/mmwrhtml/ss5710a1.htm

Climate, Weather, and Lyme Disease Modeling

Lyme Disease Models…

- Climatic variables and geographical distribution
- Weather patterns and seasonality
- Weather variation and inter-annual variation

Climate, Weather, and Lyme Disease



Estimated Effects of Projected Climate Change on the Basic Reproductive Number of the Lyme Disease Vector *Ixodes scapularis*

Nicholas H. Ogden, Milka Radojević, Xiaotian Wu, Venkata R. Duvvuri, Patrick A. Leighton, and Jianhong Wu

http://dx.doi.org/10.1289/ehp.1307799

Climate warming may have co-driven Lyme disease emergence in northeastern North America and in the future may drive substantial disease spread into new geographic regions and increase tick-borne disease risk where climate is currently suitable.

Adapted from: Ogden NH et al. 2014

Climate Change Influences on the Annual Onset of Lyme Disease in the United States

Ticks and Tick-borne Diseases 6 (2015) 615–622

Contents lists available at ScienceDirect

Ticks and Tick-borne Diseases

journal homepage: www.elsevier.com/locate/ttbdis

ELSEVIER

Original article

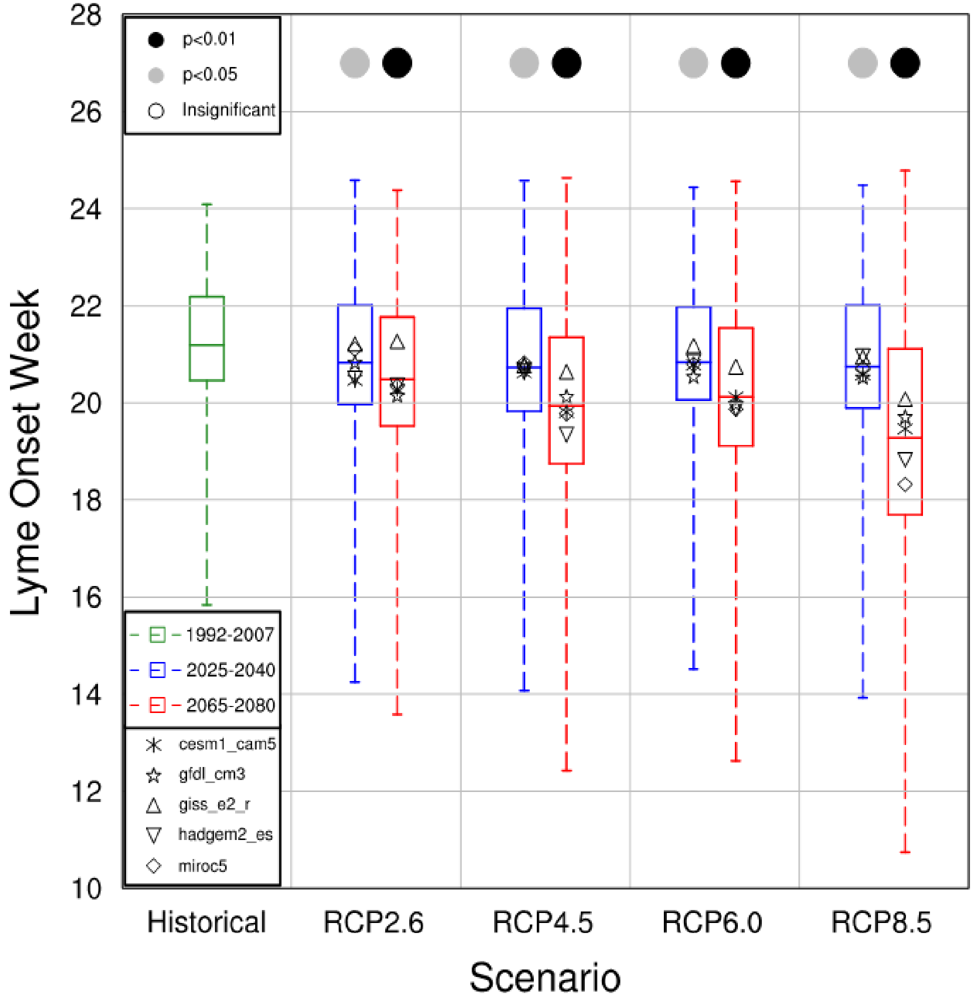
Climate change influences on the annual onset of Lyme disease in the United States

CrossMark

Andrew J. Monaghan[a,*], Sean M. Moore[b], Kevin M. Sampson[a], Charles B. Beard[c], Rebecca J. Eisen[c]

[a] Research Applications Laboratory, National Center for Atmospheric Research, 3090 Center Green Dr., Boulder, CO 80301, USA
[b] Johns Hopkins School of Public Health, 615 N. Wolfe St., Baltimore, MD 21205, USA
[c] Division of Vector-Borne Diseases, Centers for Disease Control and Prevention, 3150 Rampart Rd., Fort Collins, CO 80522, USA

Climate Change Influences on the Annual Onset of Lyme Disease in the United States



- A meteorological-based empirical model for Lyme disease onset
- Uses downscaled simulations from five global climate models and four emissions scenarios
- National average annual onset week is projected to become 0.4-0.5 weeks earlier for 2025-2040 ($p<0.05$), and 0.7-1.9 weeks earlier for 2065-2080 ($p<0.01$)

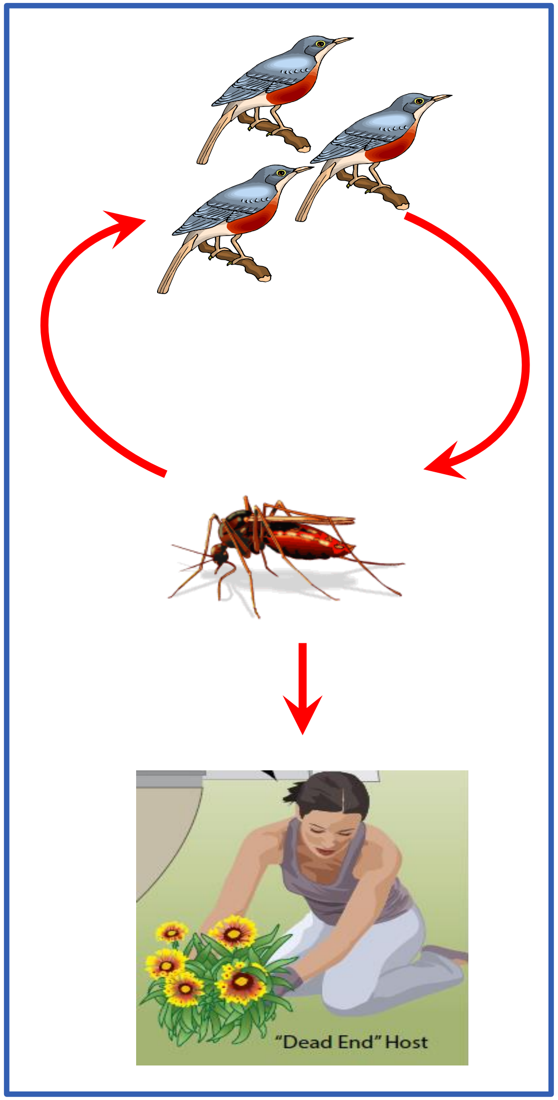
Climate, Weather, and Lyme Disease

- Minimum temperature primarily defines the northern distribution of vectors.
- Warmer temperatures may increase the reproductive capacity of ticks, leading to larger populations and greater risk for disease transmission to humans.
- Higher moisture levels allow tick survival in warmer environments.
- Temperature and moisture affect tick feeding behavior.
- Temperature (cumulative growing degree days) affects disease seasonality.
- Tick vectors will likely show earlier seasonal activity and a generally northward expansion in response to increasing temperatures.
- Longer seasonal activity and expanding geographic range of ticks will likely increase the risk of human exposure to infected tick bites.

Brownstein, J. S., T. R. Holford, and D. Fish. 2003. Environ Health Persp 111: 1152-1157
Eisen, L., R. J. Eisen, and R. S. Lane. 2002. Med Vet Entomol 16: 235-244
Yuval, B., and A. Spielman. 1990. J Med Entomol 27: 196-201
Moore, S. M., R. J. Eisen, A. Monaghan, and P. Mead. 2014. Am J Trop Med Hyg 90: 486-496

Case Study 2: West Nile Virus Infection

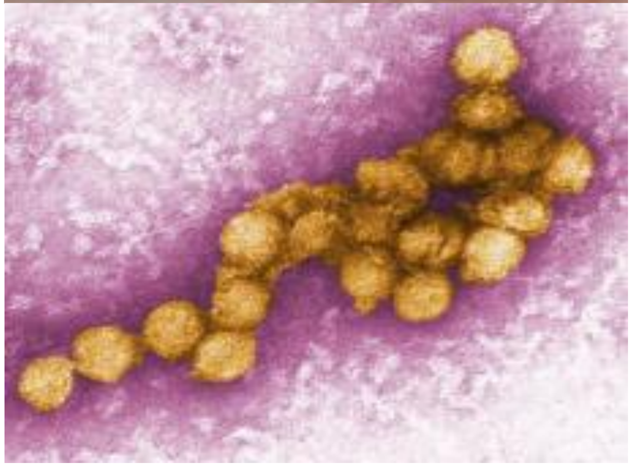
- Member of the *Flavivirus* genus in the JE virus subcomplex
- Transmitted primarily by *Culex* species mosquitoes
- Amplified by birds
- Humans and other mammals are “dead end” hosts
  - Not essential for pathogen life cycle
- Clinical syndromes:
  - West Nile fever (about 25% of cases)
  - Neuroinvasive disease (<1% of infections)



JE: Japanese encephalitis

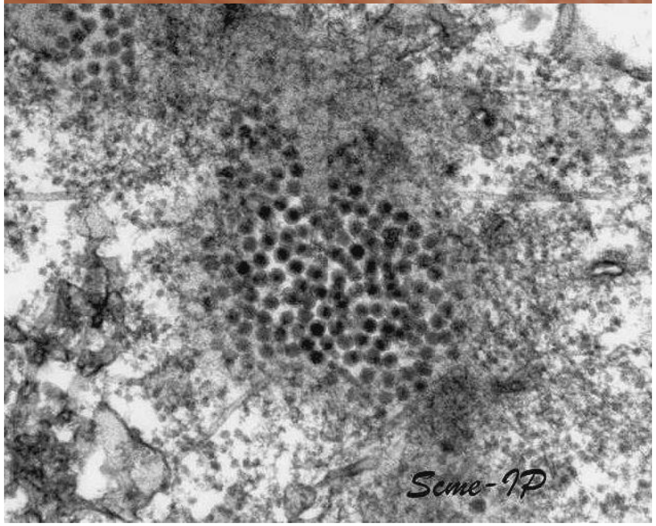
West Nile Virus Outbreak of 2012

- More than 5,600 human cases
  - 2,873 neuroinvasive disease cases
  - 286 deaths
- Largest outbreak since 2003
- Cases reported from all lower 48 states
- Focally-intense outbreak distribution
  - ~ One-third of cases reported from Texas
  - ~ Half of Texas cases reported from the 4-county area around Dallas
- Aerial spraying with insecticides was used around Dallas for the first time in almost 50 years



Factors Associated with the West Nile Virus Outbreak of 2012

- High level of WNV activity in the U.S. in 2012 was likely influenced by
  - Mild winter in 2011 - 2012
  - Early spring
  - Hot summer
- Long growing season combined with hot summer resulted in increased mosquito reproductive cycles and accelerated virus replication, facilitating WNV amplification and transmission to humans



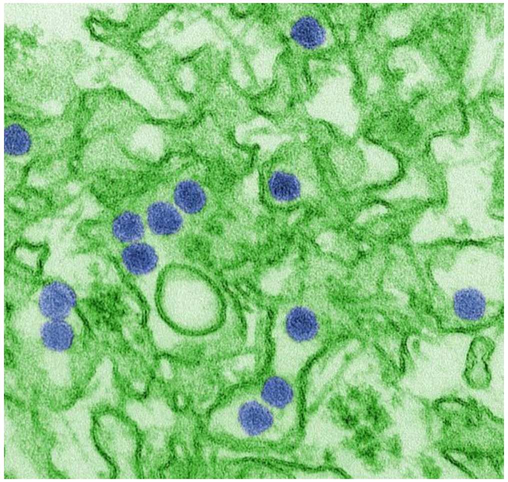
Climate, Weather, and West Nile Virus

- Temperature (e.g. milder winters, earlier onset of spring, warmer summers) influences mosquito life cycle and rate of viral replication.
- Precipitation has a significant effect, but the relationship is more complicated and varies regionally…
  - Mosquito vector species vary in the eastern and western U.S.
  - Rainfall can have different effects on the breeding habitat of these different vector species.
- Rising temperatures, changing precipitation patterns, and a higher frequency of some extreme weather events will likely influence the distribution, abundance, and prevalence of infection in the mosquito vectors by altering habitat availability and reproduction rates (of both mosquitoes and virus).
- Alterations in the distribution, abundance, and infection rate of mosquitoes will likely influence human exposure to bites from infected mosquitoes, changing the risk for human disease.

Reisen et al. 2006. J. Med. Entomol. 43: 309–317
Chuang et al, 2011. J. Med. Entomol. 48: 669–679
Morin & Comrie, 2013. PNAS; doi:10.1073/pnas.1307135110

Case Study 3: Zika virus

- Single stranded RNA virus
- Genus *Flavivirus*, family *Flaviviridae*
- Closely related to dengue, yellow fever, Japanese encephalitis, and West Nile viruses
- Primarily transmitted through the bite of an infected *Aedes* species mosquito *(Ae. aegypti* and *Ae. albopictus)*
- Other routes of transmission include:
  - From mother to child (intrauterine or perinatal)
  - Through sex, even if the infected person is asymptomatic
  - Blood transfusion (no reports from U.S.)
  - Laboratory exposure (4 reports, 1 in U.S.)
- Nonhuman and human primates are likely the main reservoirs of the virus.



Zika virus Clinical Disease Course and Outcomes

- Clinical illness is usually mild
- Symptoms last several days to a week
- Severe disease requiring hospitalization is uncommon
- Fatalities are rare
- Guillain-Barré syndrome (GBS) reported in patients following suspected Zika virus infection
  - Relationship to Zika virus infection is not known
- Zika infection in pregnancy is a cause of microcephaly and other severe brain defects

History of Zika virus

- Initially isolated in 1947 from blood of a febrile sentinel rhesus monkey during a yellow fever study in the Zika Forest of Uganda
- In 1952, the first human cases of Zika were detected. Since then, outbreaks of Zika have been reported in tropical Africa, Southeast Asia, and the Pacific Islands
- Prior to 2007, very few human cases had been reported.
- In May 2015, PAHO issued an alert regarding the first confirmed Zika virus infection in Brazil
- On January 22, 2016, CDC activated its Emergency Operations Center (EOC) to respond to the Zika outbreak in the Americas and increased reports of birth defects and Guillain-Barré syndrome in areas affected by Zika
- On February 8, 2016, following the February 1st WHO declaration of the Zika virus outbreak as a PHEIC, CDC elevated its EOC activation to Level 1, the highest level

The Spread of Zika Virus Since Discovery

1947
Discovery

1954
1st Human

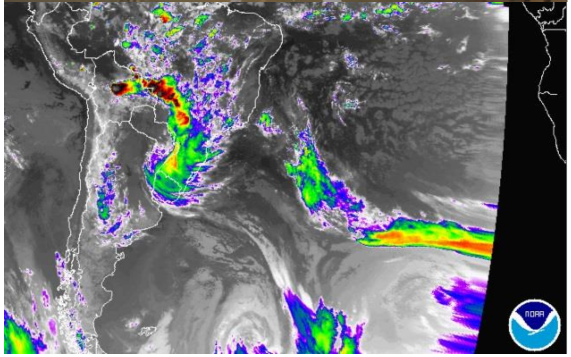
1954-2007
Asia

2007-2014
Pacific

2015
Americas

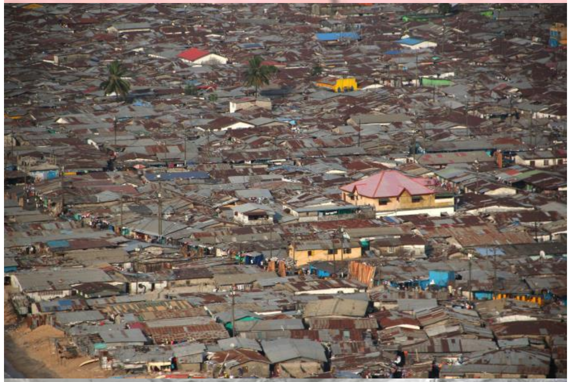
Climate, Weather, and Zika Virus

- At warmer temperatures, *Ae. aegypti* complete development from egg to adult more quickly leading to larger populations and subsequent greater transmission risks
- At warmer temperatures, virus particles replicate faster, leading to higher viral loads, which may contribute to more efficient transmission
- Precipitation is more complicated, but in general, greater amounts of rainfall have been correlated with larger mosquito populations due to increased breeding habitat

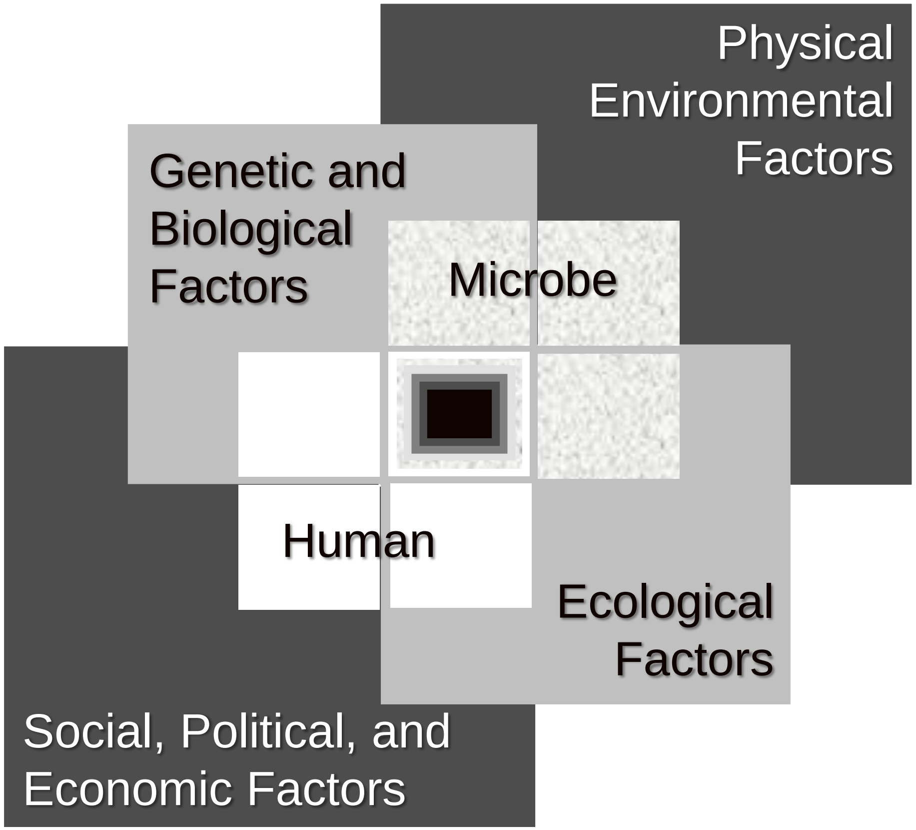


Climate, Weather, and Zika virus

- The mosquito vector *Ae. aegypti* has been present in the Americas for many years transmitting dengue virus and more recently chikungunya virus
- Mosquito populations, while potentially influenced by temperature and precipitation, are not the only factors to consider
- Other critical factors include…
  - Global travel (i.e. frequency and range of movement of infected humans)
  - Poverty, living conditions, and crowding
  - Susceptible human population
  - Limited public health resources for responding to local disease outbreaks
- The challenge is in determining what portion of the current outbreak can be attributed to climate change and weather patterns, against the background of the other contributing factors



Drivers for Disease Emergence



Convergence Model for Emerging Diseases

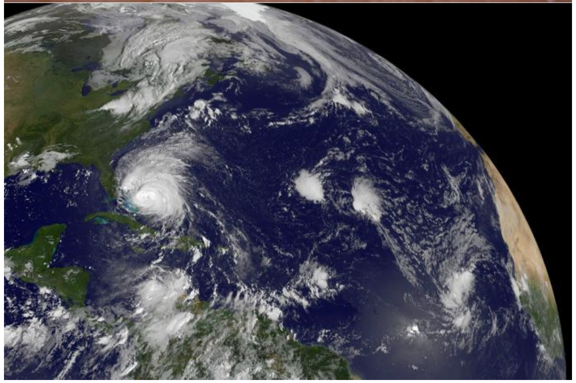
- Climate and weather
- Changing ecosystems
- Economic development and land use
- Microbial adaptation and change
- Human susceptibility to infection
- Human demographics and behavior
- Technology and industry
- International travel and commerce
- Breakdown of public health measures
- Poverty and social inequality
- War and famine
- Lack of political will
- Intent to harm

Source: Institute of Medicine 2003 report – Microbial Threats to Health

Developing a public health framework

Minimizing Adverse Health Effects of Climate-sensitive Infectious Diseases

- Public health surveillance
  - Establish baseline levels of disease occurrence
  - Track trends and monitor changes in geographic range of vectors and diseases
- Preparedness
  - Maintain capacity for detection and response
  - Develop decision-support tools
- Research
  - Develop predictive models for changes in distribution, risk of disease introductions
  - Identify cost-effective prevention methods



Prevention and Control of VBDs in a Changing Environment

Concerns that need to be addressed…

- Long-term research on climate change impact on ecology and epidemiology of VBDs
- A greater emphasis on co-benefits of climate change adaptation strategies with current public health needs
- Better understanding of potential future challenges
  - Changes in vector populations and distributions
  - Changes in duration of transmission season
  - Increase in exotic introductions
  - More rapid environmental degradation of pesticides
- Potential need for resistance management strategies and options, including a greater reliance on validated IPM approaches

Conclusion

- Climate change will have wide-ranging health impacts
- An integrated understanding of climate, ecology, and epidemiology is critical for predicting and averting epidemics of infectious diseases
- Preparation to prevent, mitigate, and adapt to emerging infectious disease threats related to climate change include…
  - A continued investment in disease surveillance to track disease trends
  - Maintenance of a strong national public health system so that when diseases occur in new areas, they will be quickly detected, reported, and responded to
  - Development of decision-support tools and adaptation strategies
  - An investment in environmental data collection and disease/climate modeling efforts applicable to future climate scenarios

Thank you for your time and interest!

E-mail: cbeard@cdc.gov

Resources:
http://www.cdc.gov/lyme/
http://www.cdc.gov/westnile/
http://www.cdc.gov/zika/index.html
http://www.cdc.gov/ticks/index.html
http://www.cdc.gov/climateandhealth/default.htm
https://health2016.globalchange.gov

Acknowledgments: Numerous staff of CDC's Division of Vector-Borne Diseases