IMPROVING UNDERSTANDING AND PREDICTION OF VECTOR- AND WATER-BORNE DISEASES

EXPLORING THE PROSPECT OF EARLY WARNING SYSTEMS

HUNTER JONES, CLIMATE AND HEALTH PROJECT MANAGER

NOAA CLIMATE PROGRAM OFFICE

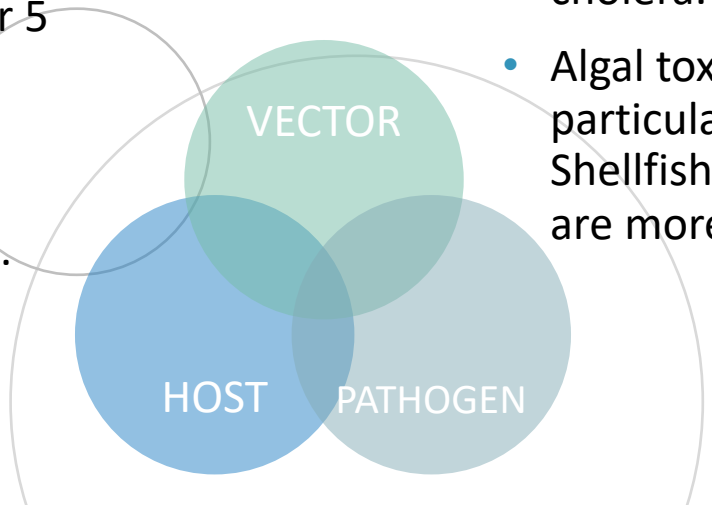
PREDICTING VECTOR- AND WATER- BORNE DISEASE

Pathogens and their vectors are influenced by environmental changes. Understanding the mechanisms by which vector and pathogen habitat suitability, behavior, survivability, and reproduction are influenced is essential to providing early warning and long-term planning for the diseases they cause.

FACTS FROM THE WORLD HEALTH ORGANIZATION

Vector-borne disease

- Vector-borne diseases account for more than 17% of all infectious diseases, causing more than 700 000 deaths annually.
- More than 3.9 billion people in over 128 countries are at risk of contracting dengue, with 96 million cases estimated per year.
- Malaria causes more than 400 000 deaths every year globally, most of them children under 5 years of age.
- Other diseases such as Chagas disease, leishmaniasis and schistosomiasis affect hundreds of millions of people worldwide.

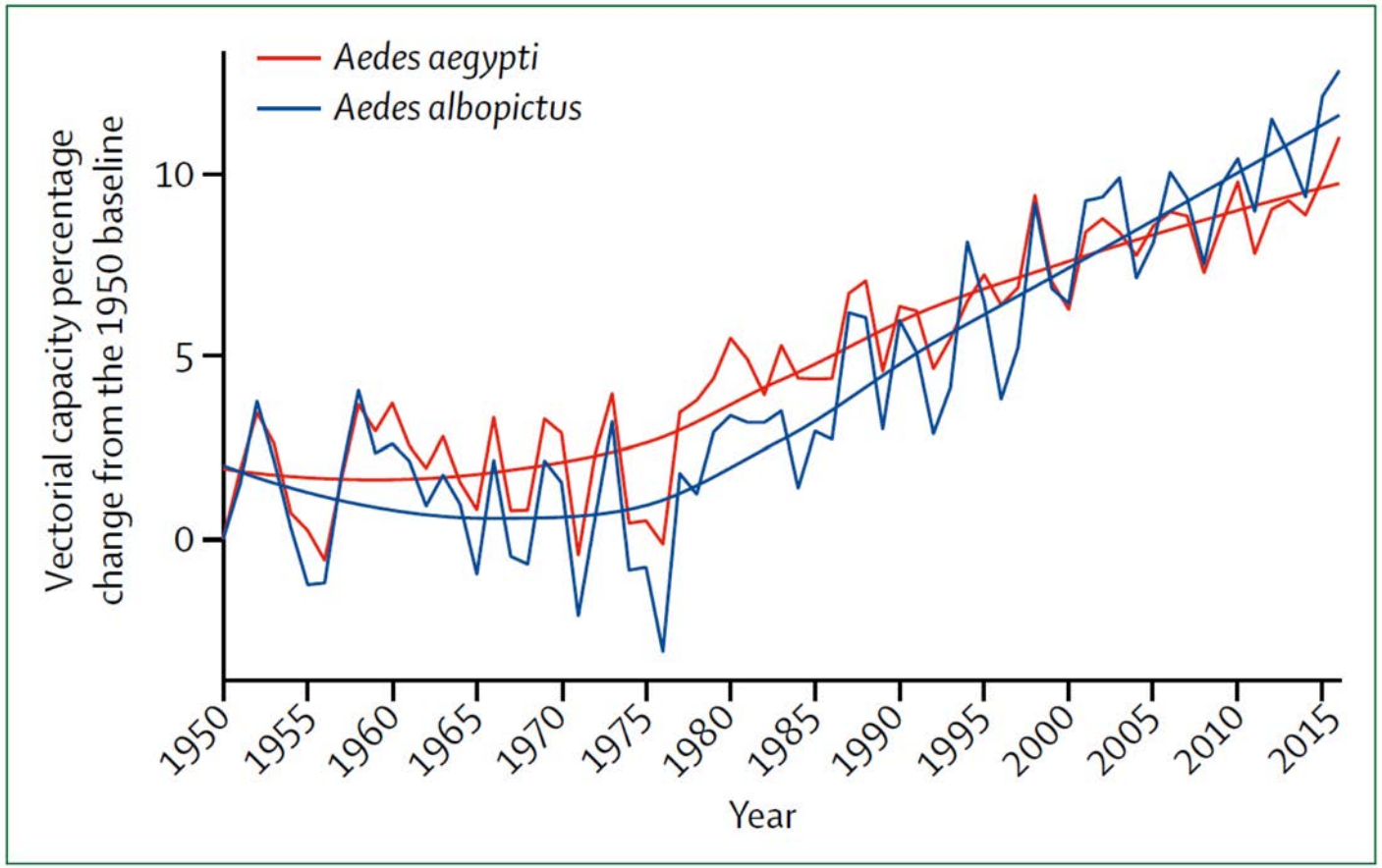


Water-borne disease

- Contaminated water can transmit diseases such diarrhoea, cholera, dysentery, typhoid, and polio. Contaminated drinking water is estimated to cause 485 000 diarrhoeal deaths each year.
- Researchers have estimated that each year there are 1.3 million to 4.0 million cases of cholera, and 21 000 to 143 000 deaths worldwide due to cholera.
- Algal toxins are generated during blooms of particular naturally occurring algal species. Shellfish such as mussels, scallops and oysters are more likely to contain these toxins than fish.

https://www.who.int/news-room/fact-sheets

LANCET: CHANGES IN VECTORIAL CAPACITY FOR DENGUE



- Indicator 1.8:
  Climate-sensitive infectious diseases

  In 2016, global vectorial capacity of for the transmission of dengue virus was 9.1% (A. aegypti) and 11.1% (A. albopictus) above the 1950s baseline.

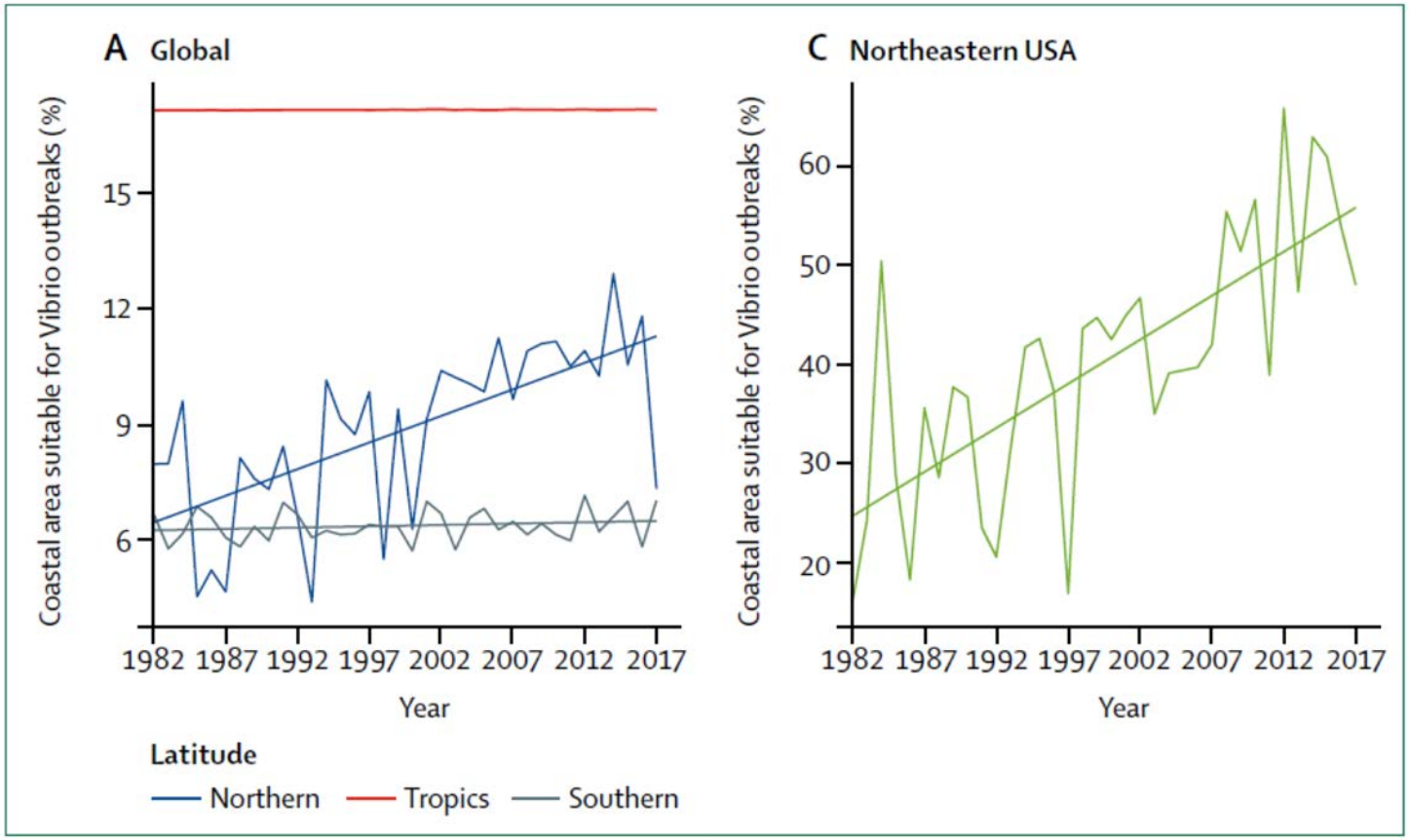
  Vectorial capacity represents the ability of a mosquito to transmit the pathogen to a host and is calculated from the following variables:

  - **number** of **female** mosquitoes per host
  - daily blood **feeding rate**
  - **transmission rate** among exposed mosquitoes
  - probability of daily **survival**
  - extrinsic **incubation** period

- Lancet Countdown 2018

Kramer, L. D., & Ciota, A. T. (2015). Dissecting vectorial capacity for mosquito-borne viruses. Current Opinion in Virology, 15, 112–118. doi:10.1016/j.coviro.2015.10.003

LANCET: CHANGES IN ENVIRONMENTAL SUITABILITY FOR VIBRIOS

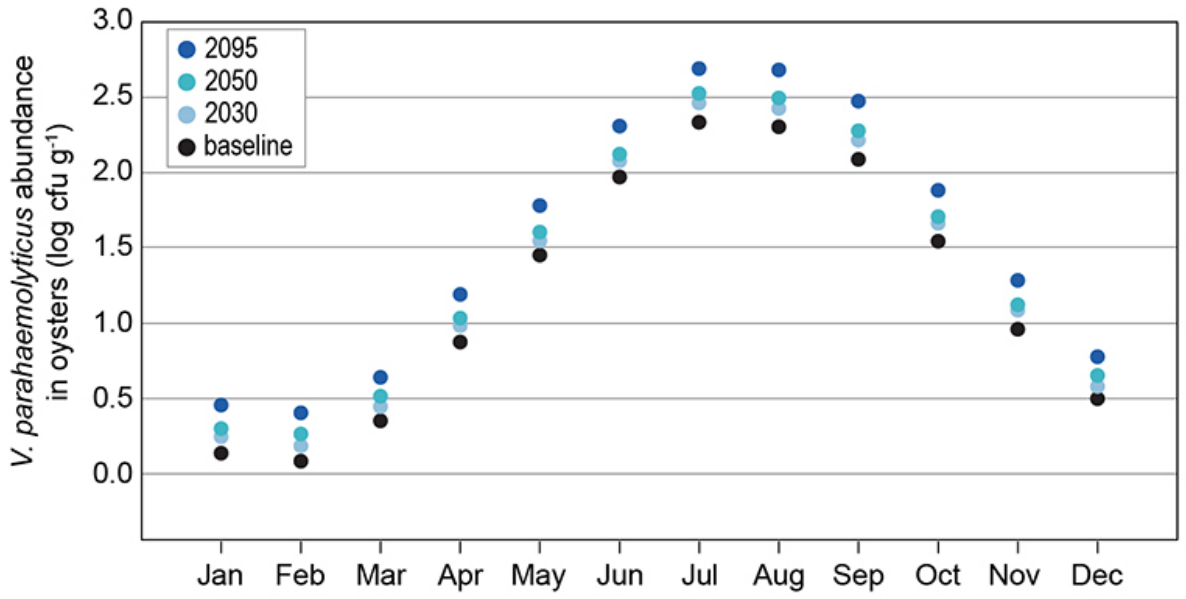


- Indicator 1.8:
  Climate-sensitive infectious diseases
  - Vibrio infections in the Baltic and US northeast increased by 24% and 27% from the 1980s. The environmental suitability for Plasmodium falciparum has increased by 20.9% in highland areas of Africa since the 1950s.
  - According to the CDC, Vibrio species which are detrimental to human health include:
    - *Vibriosis*
      - *V. Parahaemolyticus*
      - *V. alginolyticus*
      - *V. vulnificus*
    - *Cholera*
      - *V. cholerae*

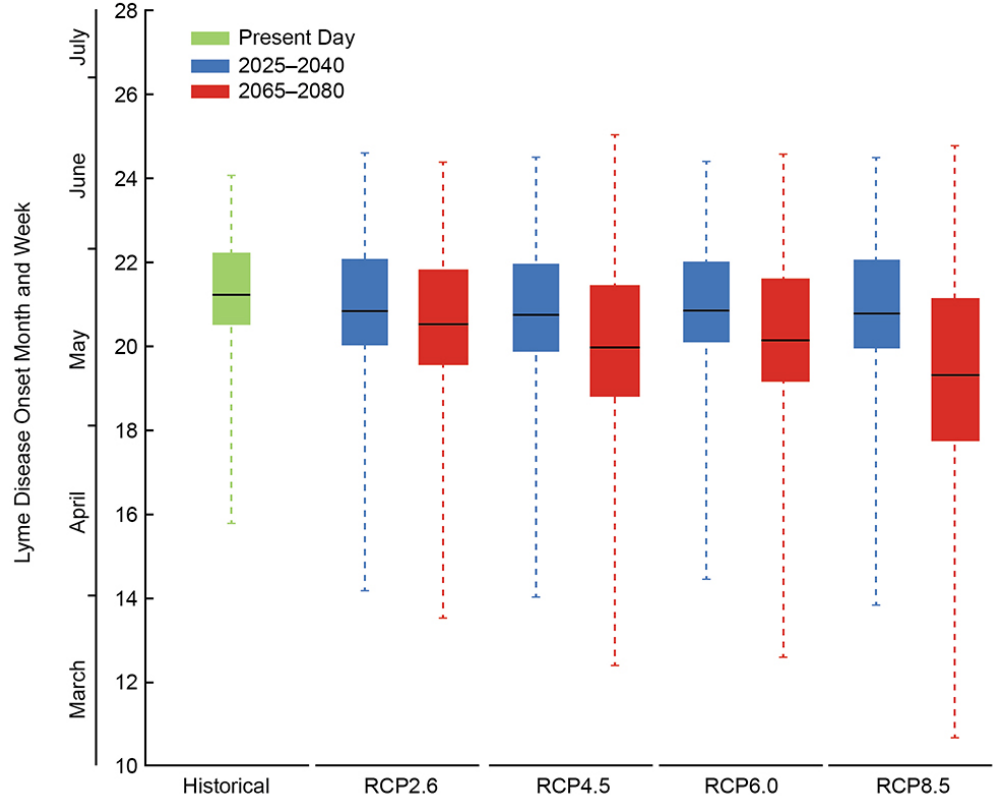
- Lancet Countdown 2018

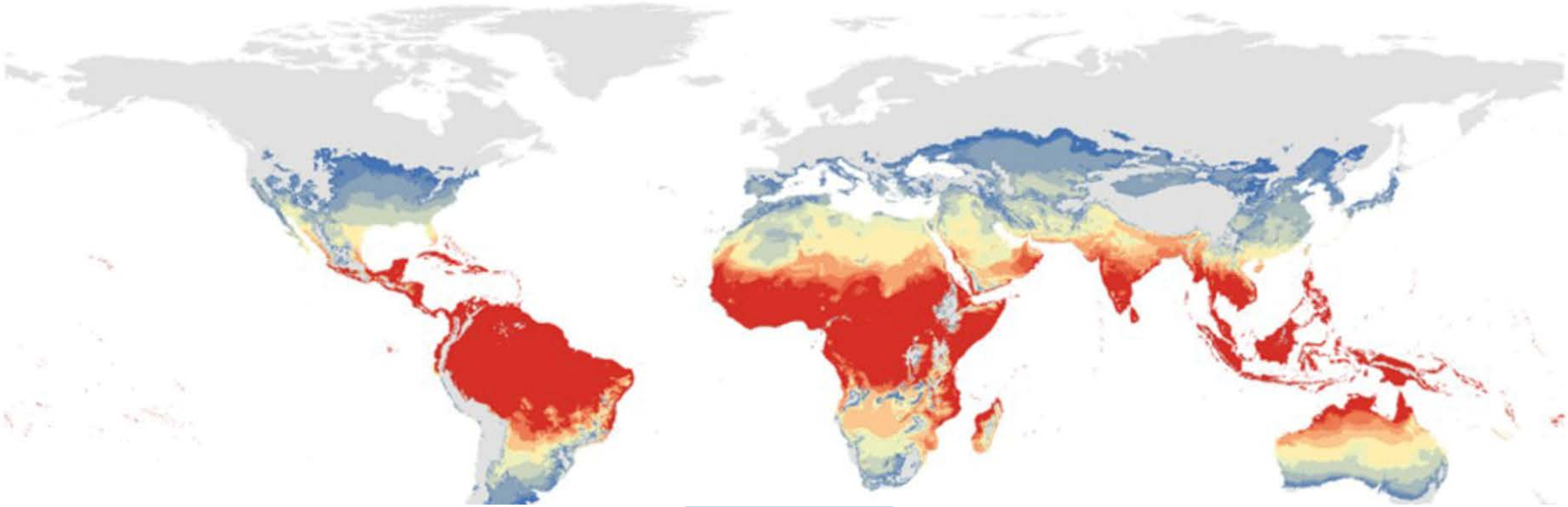
CLIMATE AND HEALTH ASSESSMENT - FUTURE PROJECTIONS

Projection of *V. Parahaemolyticus* abundance in oysters through 2019



Projected changes in Lyme Disease onset week through 2018





THE GOOD NEWS

These pathogens and vectors are all influenced by their environments, and we are getting better at understanding, modeling, and anticipating environmental changes on weather and climate timescales.

How can the earth system modeling community help?

Source: Sadie J. Ryan, Colin J. Carlson, Erin A. Mordecai, and Leah R. Johnson
Credit: Koko Nakajima/NPR
https://www.npr.org/sections/goatsandsoda/2019/03/28/707604928/chart-where-disease-carrying-mosquitoes-will-go-in-the-future

Predicting Climate Sensitive Infectious Diseases to Protect Public Health and Strengthen National Security

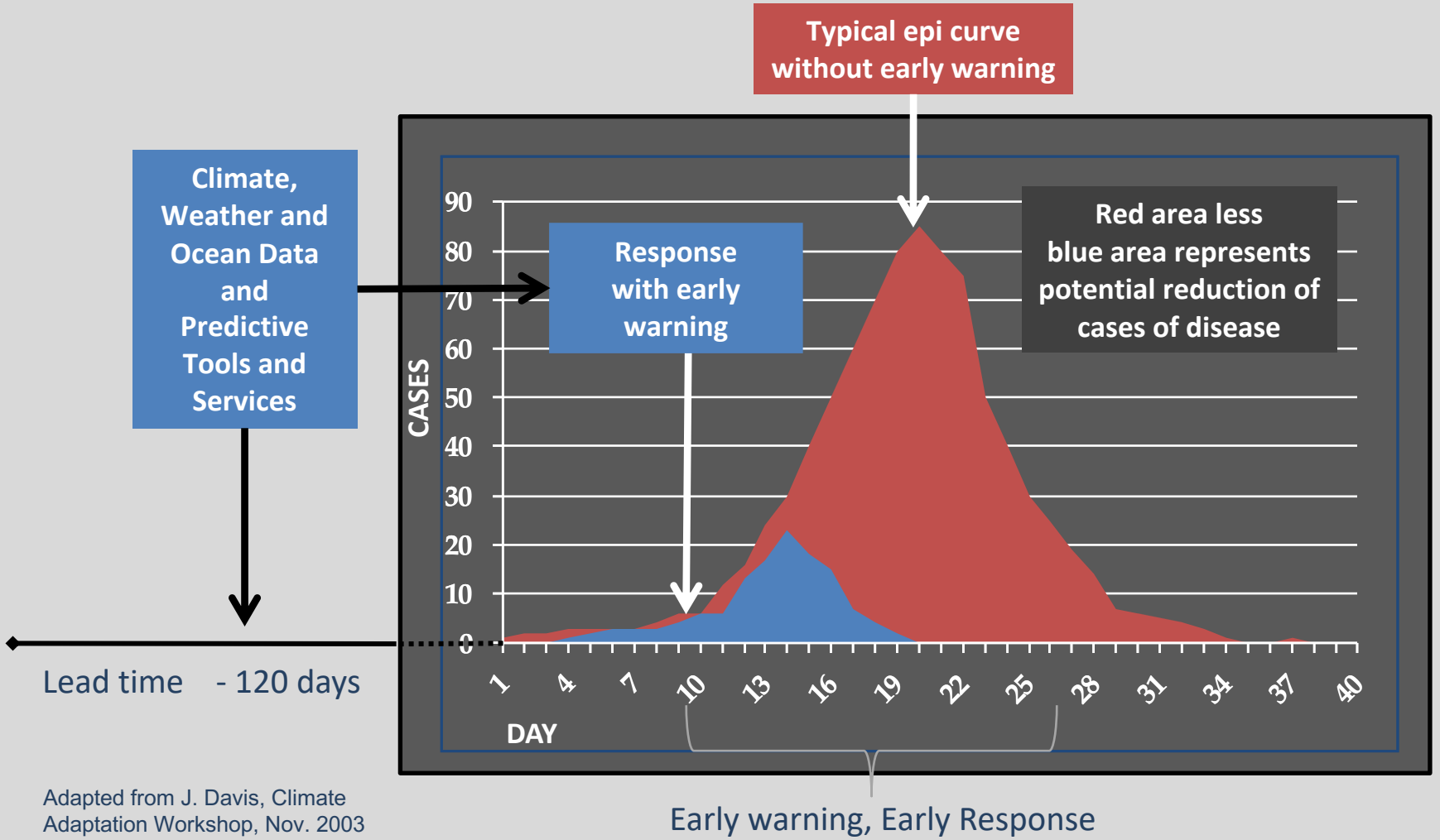
- While NOAA, NASA, and other agencies have supported research on this topic, the activities are not well integrated nor well used by decision makers for planning, preparing and building resilience.
- Activities were conducted under the auspices of the USGCRP Interagency Group on Integrated Modeling (IGIM), the USGCRP Interagency Crosscutting Group on Climate Change and Human Health (CCHHG), and the Pandemic Prediction and Forecasting Science and Technology Working Group (PPFST).

Key takeaways from the report include needs for:

- **Engaging the Academic Community**
- Identifying sustainable **institutional design** & best practices
- **Interagency and Academic partnership arrangements** for joint product development.
- **Global Risk Mapping** to support troops abroad
- **Seasonal Forecasts for Health** early warning
- **Platform(s) to share data** from earth observation, environmental sampling, public health, and socio-economic data sets

Innovation challenges to encourage novel solutions

GETTING AHEAD OF THE CURVE: CHANGING THE CULTURE TO PREDICTION, PLANNING, AND PREVENTION

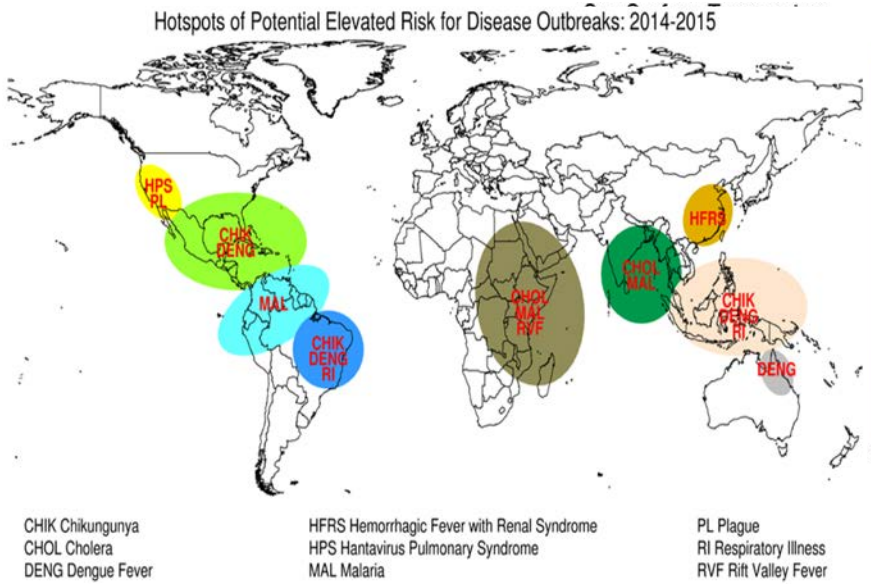


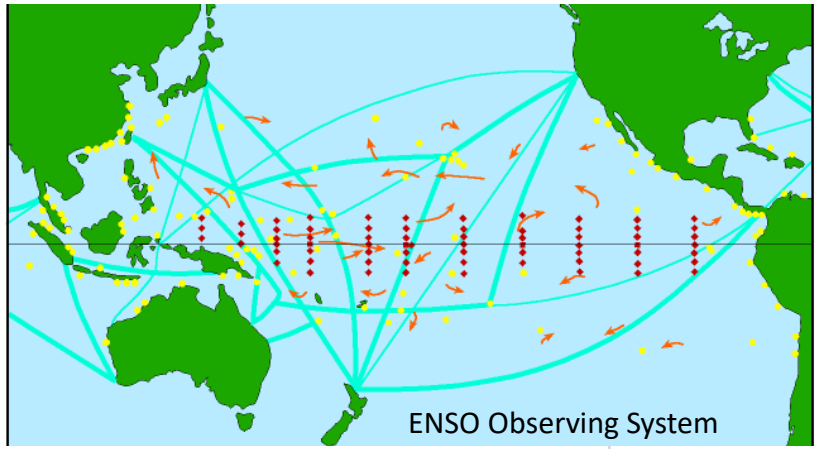
Adapted from J. Davis, Climate Adaptation Workshop, Nov. 2003

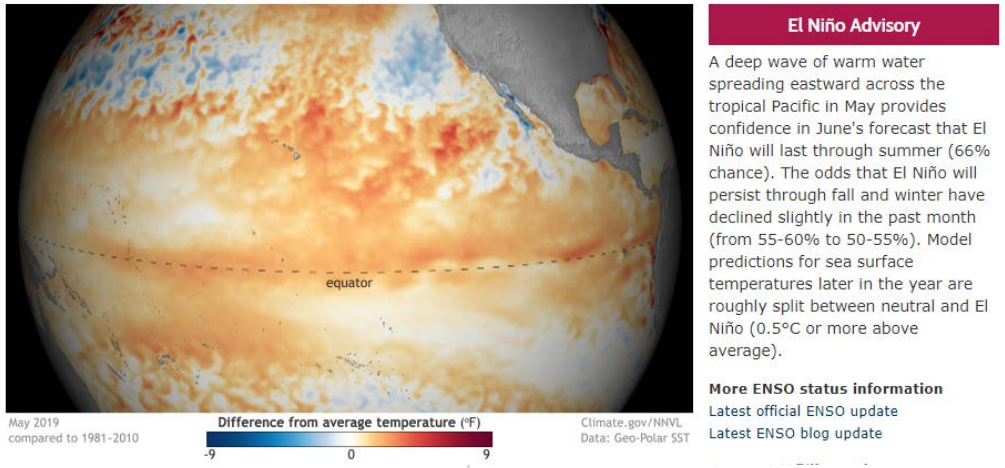
Enhancing Public Health Engagement, Outreach, and Feedback throughout

Observing Systems, Prediction, and Early Warning

- Sustained environmental observing systems are critical for supporting research, predictions, and ultimately more reliable early warning for health.
- Skillful predictions of ENSO and other such climate modes enables warnings of increased likelihood of climate-linked health impacts such as disease vector abundance, range, and behavior which lead to diseases from Chagas to Zika.







http://www.pmel.noaa.gov/tao/elnino/ https://www.eol.ucar.edu/projects/dynamo

WATER-BORNE DISEASES

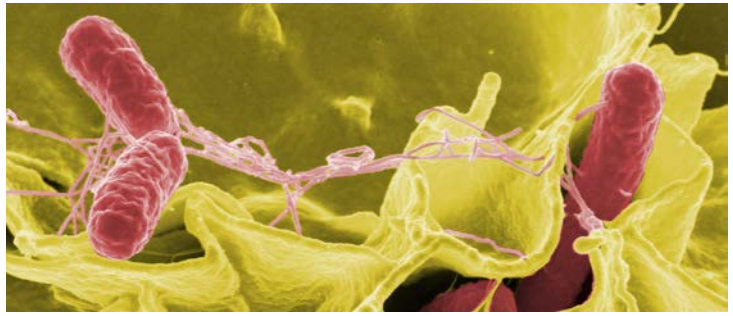
- NOAA NCCOS Models for Vibrio vulnificus and Vibrio parahaemolyticus
- Ecological Forecasting Roadmap

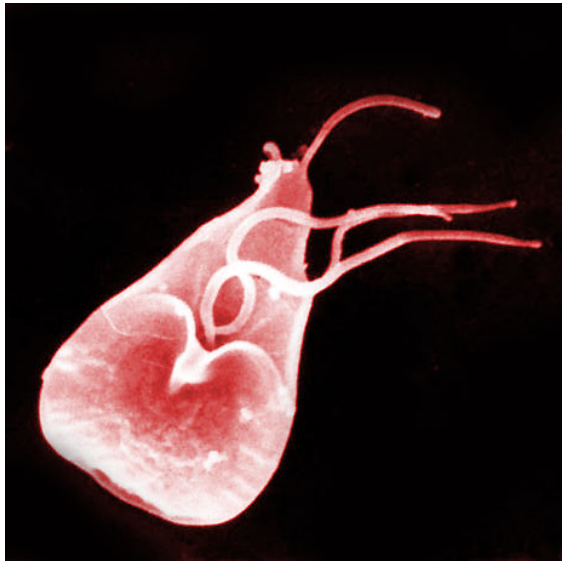
NASA Earth Observatory

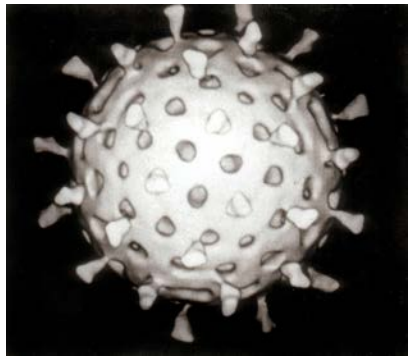
A HANDFUL OF PATHOGENS ARE AMONG THE MOST PROLIFIC HEALTH CONCERNS

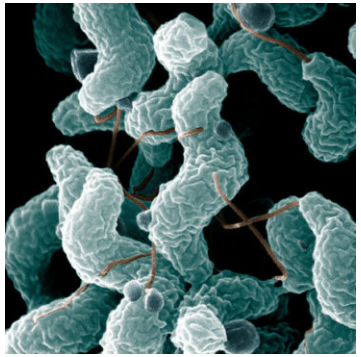
Up to 12% of GI issues stem from waterborne pathogens in the US, and 97% of all waterborne illnesses in the US are caused by:

- Norovirus
- Rotavirus
- Adenovirus
- Campylobacter Jejuni
- E. coli O157:H7
- Salmonella enterica
- Cryptosporidium
- Giardia



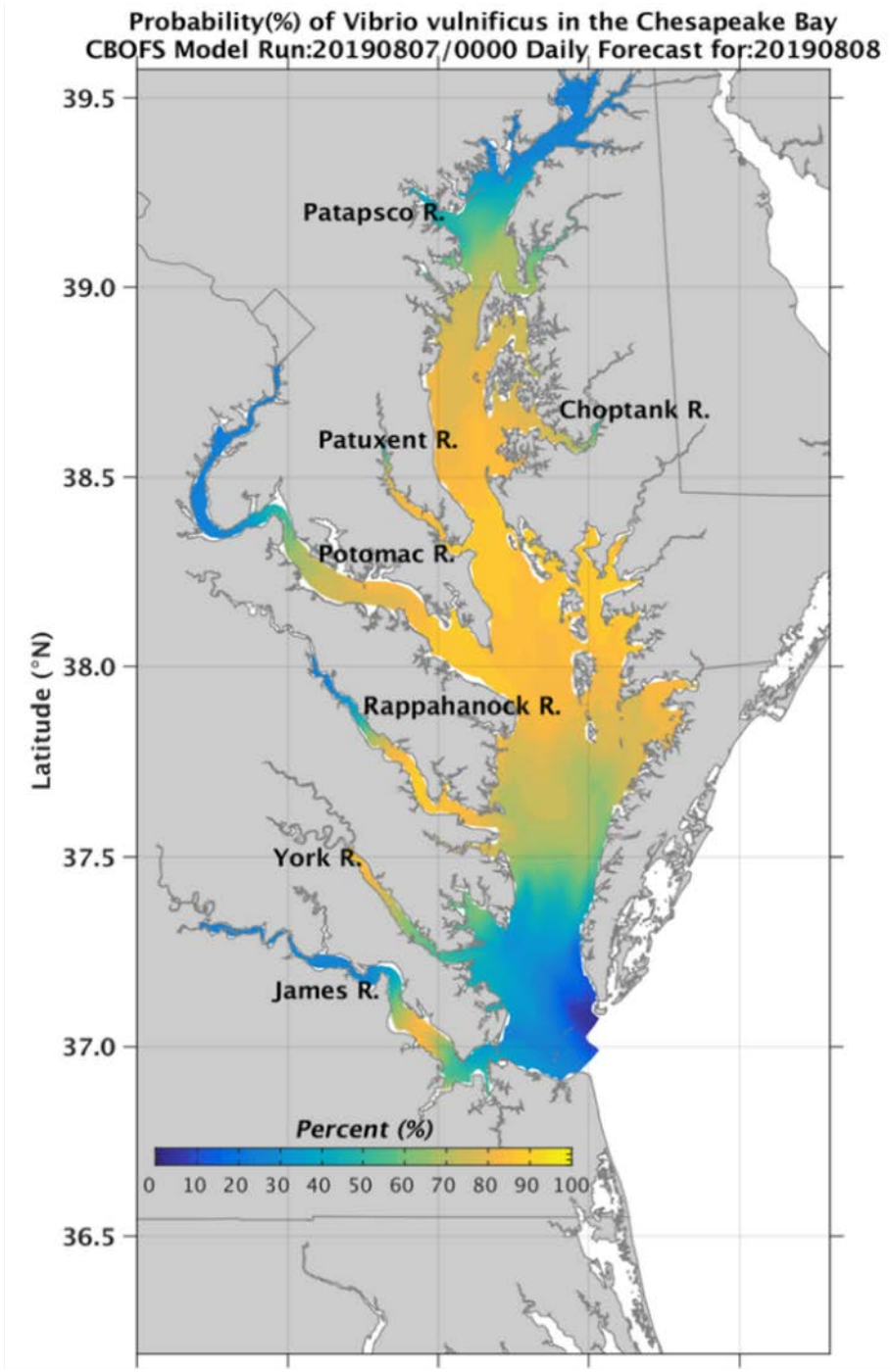






…but all are affected by climate changes

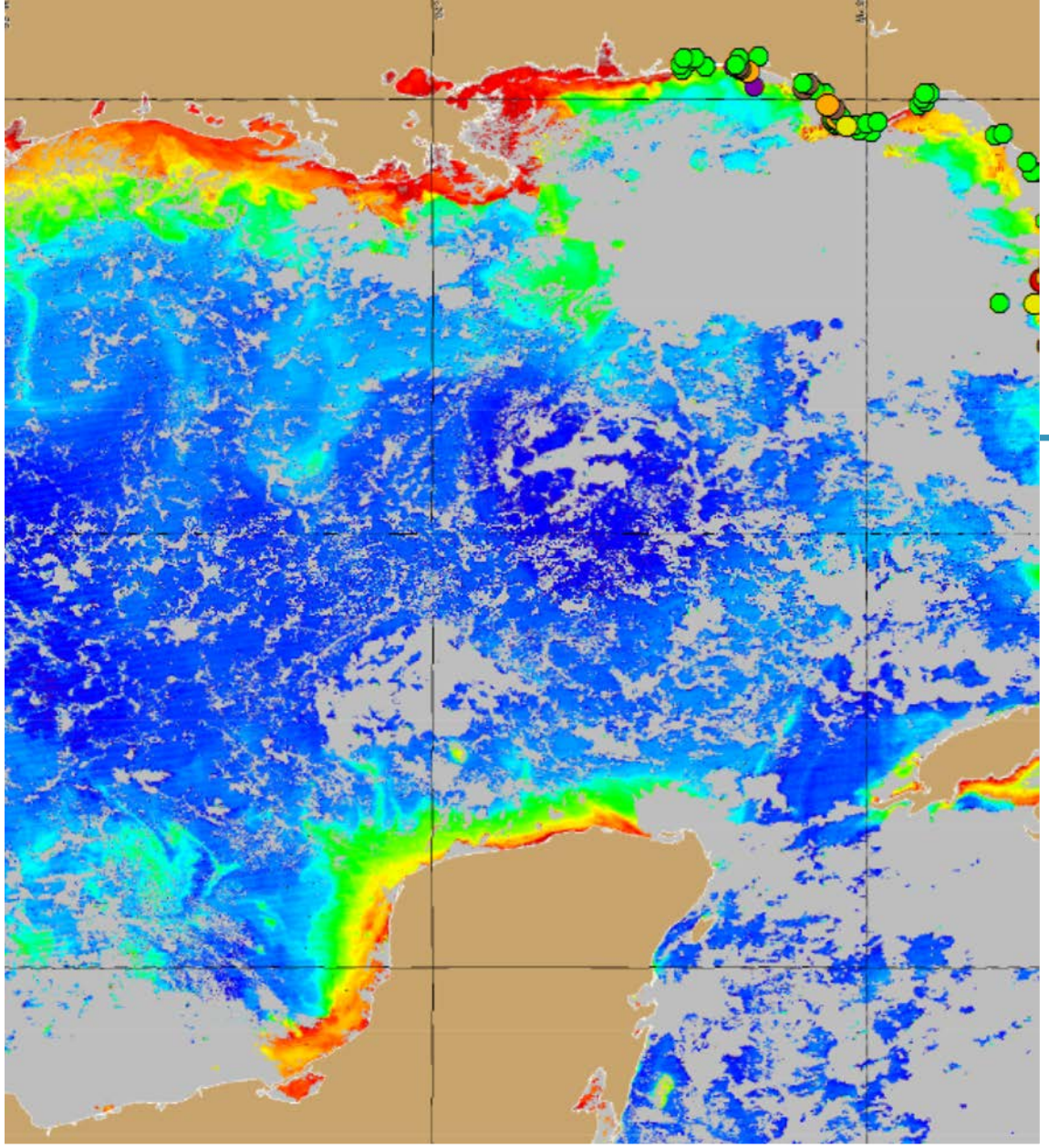
Trtanj, J., L. Jantarasami, J. Brunkard, T. Collier, J. Jacobs, E. Lipp, S. McLellan, S. Moore, H. Paerl, J. Ravenscroft, M. Sengco, and J. Thurston, 2016: Ch. 6: Climate Impacts on Water-Related Illness. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 157–188. http://dx.doi.org/10.7930/J03F4MH4



NCCOS VIBRIO MODEL

- *Vibrio vulnificus* often transmitted through skin leisions in contaminated water.
- *Vibrio parahaemolyticus* often results from ingestion of raw or undercooked seafood.
- The NCCOS (logistic regression) models use sea surface temperature and salinity to estimate the likelihood of presence of these species.
- One challenge of producing this information is a lack of observations. In some cases, Vibrio models use 2m temperature to estimate SST because there is not enough in-situ data.

Jacobs, J. M., Rhodes, M. M. R., Brown, C. W., Hood, R. R., Leight, A., Long, W., & Wood, R. (2010). Predicting the distribution of Vibrio vulnificus in Chesapeake Bay.



From 4 October 2018 Gulf of Mexico Harmful Algal Bloom Bulletin: Karenia breviscell concentration sampling.

THE ECOLOGICAL FORECASTING ROADMAP

- NOAA's Ecological Forecasting Roadmap is designed to mainstream and institutionalize NOAA's roles in ecological forecasting science, service and stewardship while optimizing sustainability of outcomes of societal benefit.
  - Priority areas:
    - Harmful Algal Blooms
    - Hypoxia
    - Pathogens
    - Habitat

https://aamboceanservice.blob.core.windows.net/oceanservice-prod/ecoforecasting/noaa-ecoforecasting-roadmap.pdf

VECTOR-BORNE DISEASES

Understanding the risk of VBD

Transmission pathways

Important variables and findings

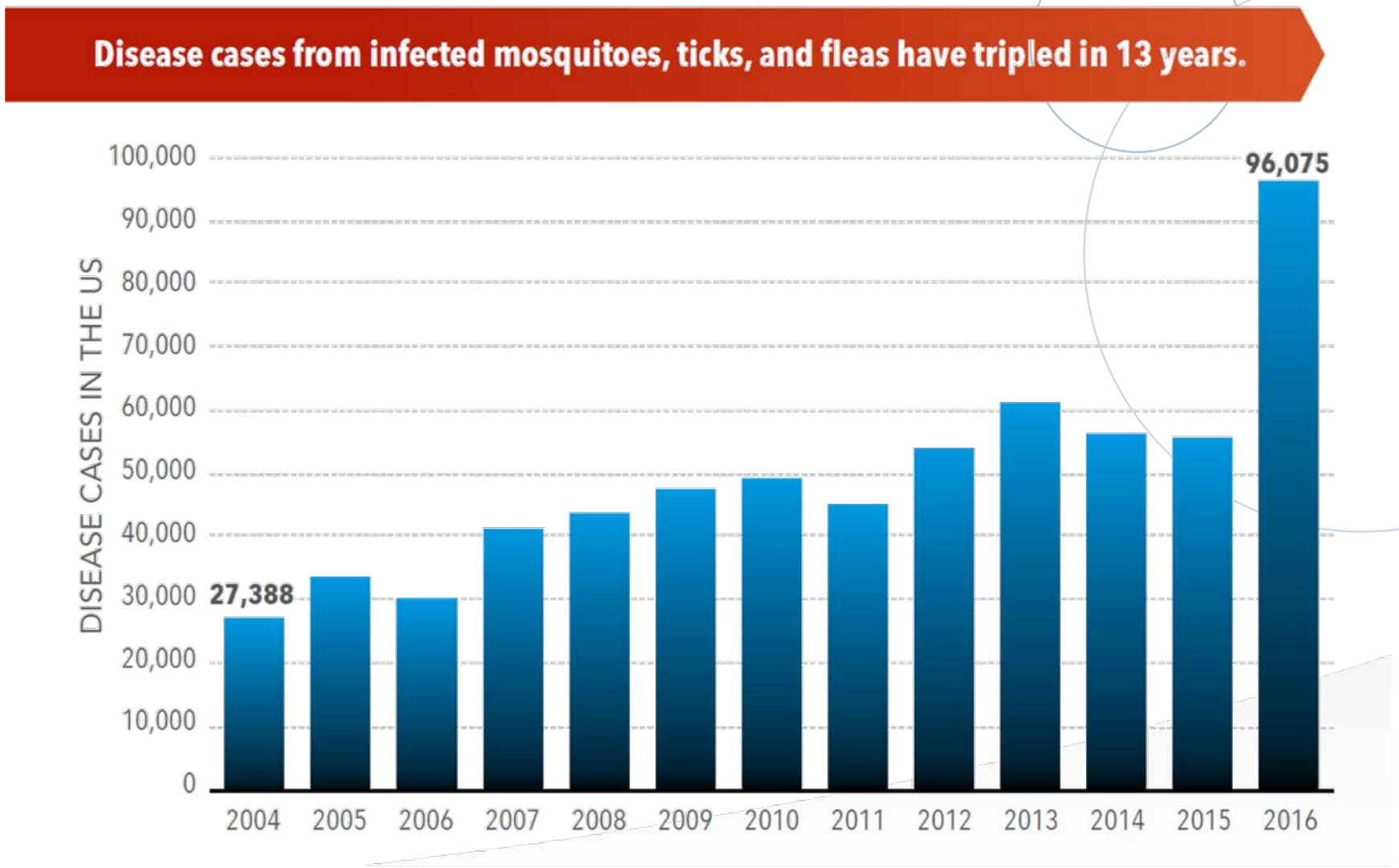
Existing models of VBD

Operational examples

US VBD CASES ARE ON THE RISE

Lyme Disease and West Nile Virus are the two most common diseases transmitted by vectors, the former by ticks and the latter by mosquitos.

Between 2004 and 2016, nine new germs spread by mosquitoes and ticks were discovered or introduced into the United States.



https://www.cdc.gov/vitalsigns/vector-borne/infographic.html#graphic1

A HANDFUL OF ARTHROPODS ARE AMONG THE MOST PROLIFIC DISEASE VECTORS

Disease vectors carry and transmit pathogens. Fortunately we can focus on a small handful that cause most of the problems.

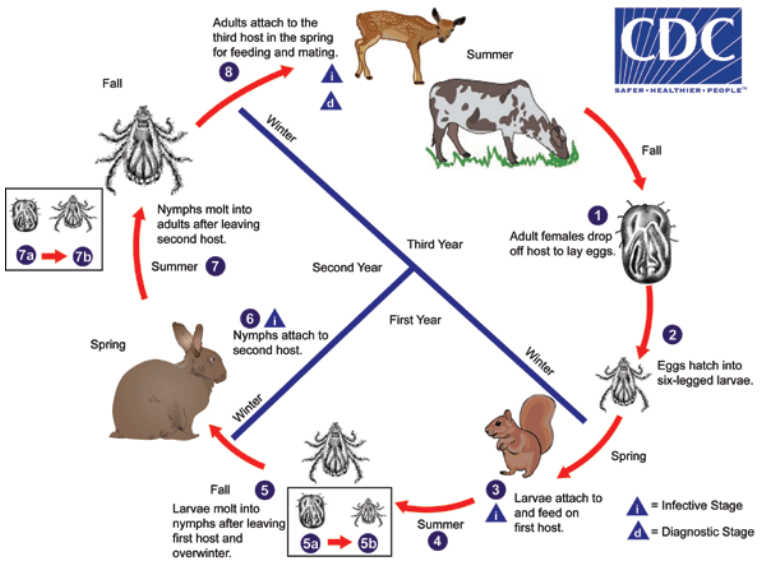
- Culex, Aedes, and Anopheles **mosquitos** can transmit West Nile Virus, Malaria, Zika, Chikungunya, Dengue, and many other illnesses.
- **Ticks** can transmit diseases such as Lyme and Rocky Mountain Spotted Fever.
- **Kissing bugs** are known to transmit Chagas disease.
- **Fleas** can transmit typhus and plague.

TRANSMISSION PATHWAYS

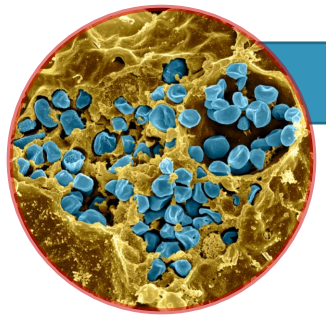
At each step in a transmission pathway, environmental conditions may influence critical factors and may enhance or diminish the likelihood of transmission.

Understanding the complex ways that the environment can influence these pathways, and the complex interactions of the pathogens, vectors, and hosts can improve our ability to predict and provide early warning for vector-borne diseases.

Climate Impacts on Tularemia Transmission



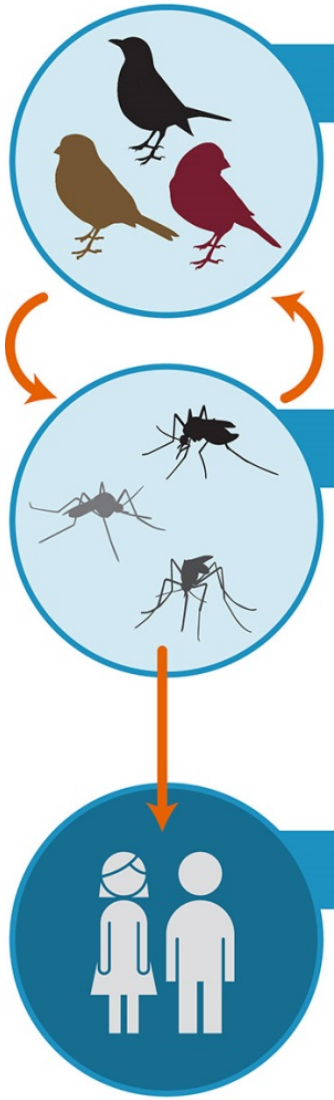
Example Three-Host Ixodid Tick Life Cycle



Pathogen
Tularemia bacteria

While most viral pathogens cannot survive well without a host, others such as bacteria can survive for weeks in a suitable environment.

Climate Impacts on West Nile Virus Transmission



Natural Host
Birds

Warmer winters, longer frost-free season, and earlier spring arrival may influence the migration patterns and fledging survival of birds that are the natural host of West Nile virus.

Key species: American robins, house finches, and house sparrows.

Insect Vector
Mosquitoes

Rising temperature, changing precipitation patterns, and a higher frequency of extreme weather events are likely to influence the distribution and abundance of mosquitoes that transmit West Nile virus by altering aquatic habitat availability and mosquito and viral reproduction rates.

Key species: *Cx. tarsalis*, *Cx. pipiens*, *Cx. quinquefasciatus*.

Incidental Host
Humans

Humans are not central to the West Nile virus transmission cycle, but can suffer serious health consequences if infected. Changing weather patterns will likely impact human behavior and exposure to mosquitoes that carry West Nile virus. Mosquito control or personal protection practices like wearing long-sleeves or repellent can reduce the risk of infection.

Adapted from USGCRP Climate and Health Assessment

COMPLEX VECTOR-ENVIRONMENT RELATIONSHIPS

- Precipitation
- Elevation
- Temperature
- Humidity
- Solar Exposure
- Human Behavior (water barrels)

?

- Fecundity
- Larval development
- Sex ratio
- Migratory patterns
- Survival
- Feeding ecology
- Habitat availability

Beard, C.B., R.J. Eisen, C.M. Barker, J.F. Garofalo, M. Hahn, M. Hayden, A.J. Monaghan, N.H. Ogden, and P.J. Schramm, 2016: Ch. 5: Vectorborne Diseases. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* U.S. Global Change Research Program, Washington, DC, 129–156. http://dx.doi.org/10.7930/J0765C7V

SELECTED FINDINGS

FROM THE USGCRP CLIMATE AND HEALTH ASSESSMENT

Both Lyme Disease and West Nile Virus have Environmental Links

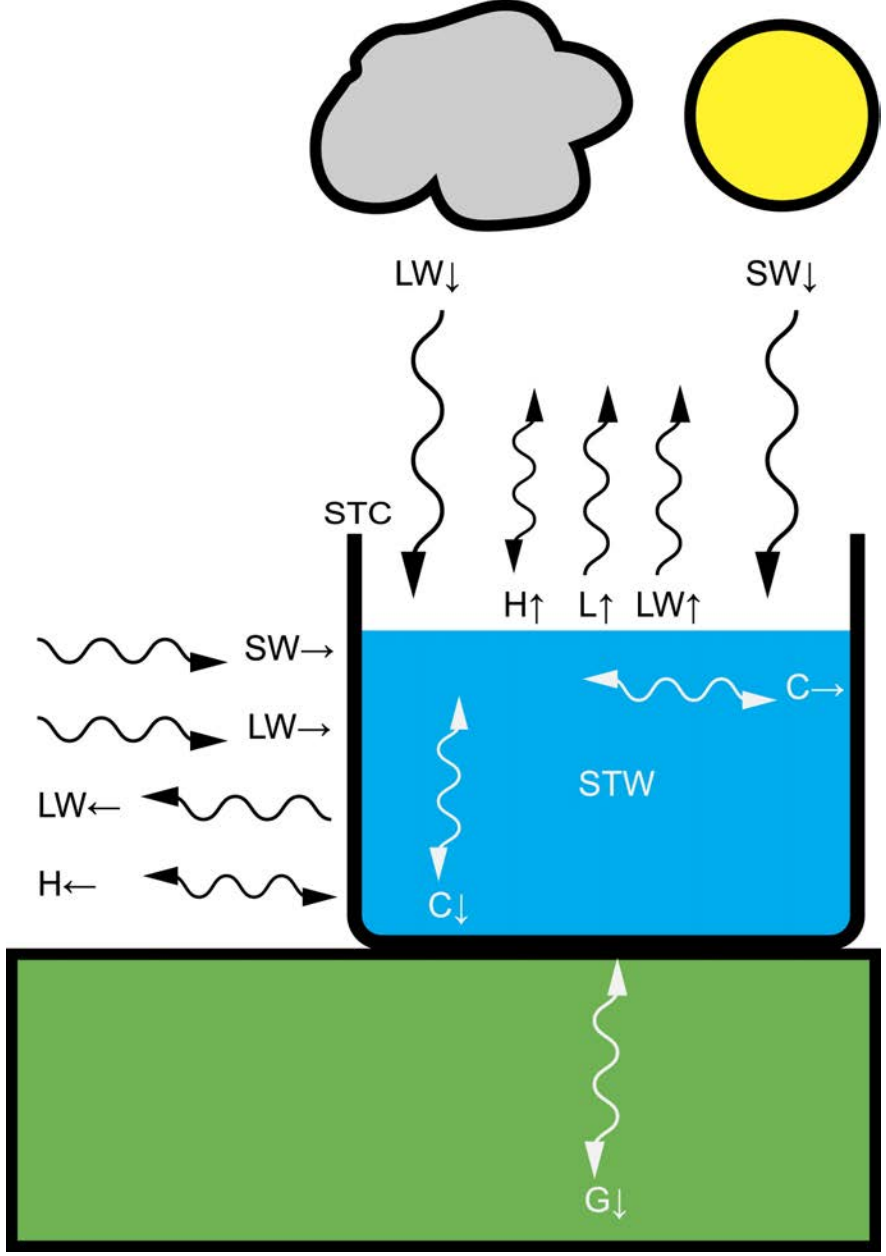
Lyme Disease

- Seasonal and year-to-year variation in case counts is high.
- The week of onset of Lyme disease differs by as much as 1- weeks year-to-year (growing degree days as indicator).
- Too high or low temps increases mortality rates, but humidity increases increase survival. Both variables influence host-seeking.
- Low minimum temperatures limit the range of ticks.

West Nile Virus

- Mosquitos respond much more quickly than ticks to climate and weather drivers.
- The length of the winter limits mosquito range.
- Bird migrations play a role in the availability of natural hosts.
- Warm temperatures accelerate biting rates, viral replication, and other aspects of the mosquito life & transmission cycle.
- Precipitation creates breeding sites.

Beard, C.B., R.J. Eisen, C.M. Barker, J.F. Garofalo, M. Hahn, M. Hayden, A.J. Monaghan, N.H. Ogden, and P.J. Schramm, 2016: Ch. 5: Vectorborne Diseases. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* U.S. Global Change Research Program, Washington, DC, 129–156. http://dx.doi.org/10.7930/J0765C7V



EXAMPLE: THE WHATCH'EM MODEL FOR CONTAINER HABITATS

- WHATCH'EM is an energy balance model that was developed to predict water height and temperature in the types of small containers (rubber tires, bottle caps, etc…) that mosquitos often lay eggs in.
- The model requires meteorological inputs to generate its complex, nonlinear predictions:
  - Air temperature
  - Humidity
  - Precipitation
  - Cloud cover
  - Container characteristics

Steinhoff, D. F. *et al.* (2016) 'WHATCH ' EM : A Weather-Driven Energy Balance Model for Determining Water Height and Temperature in Container Habitats for Aedes aegypti', 20(24). doi: 10.1175/EI-D-15-0048.1.

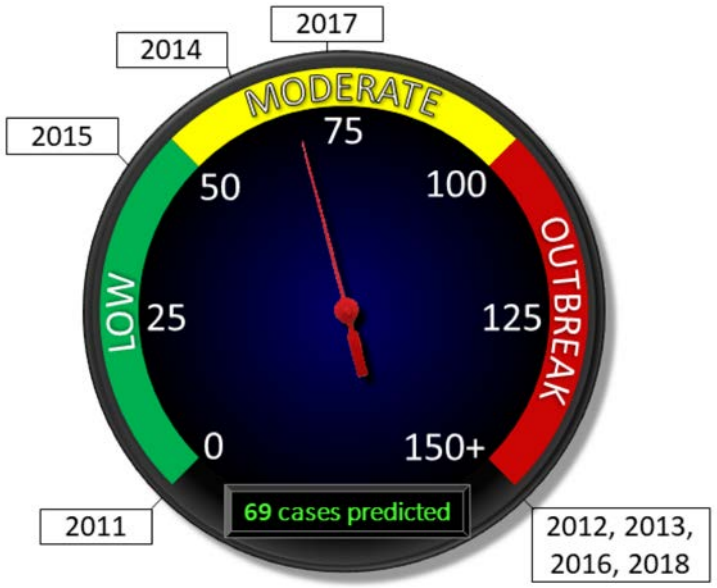
POTENTIAL APPLICATION: VECTOR CONTROL

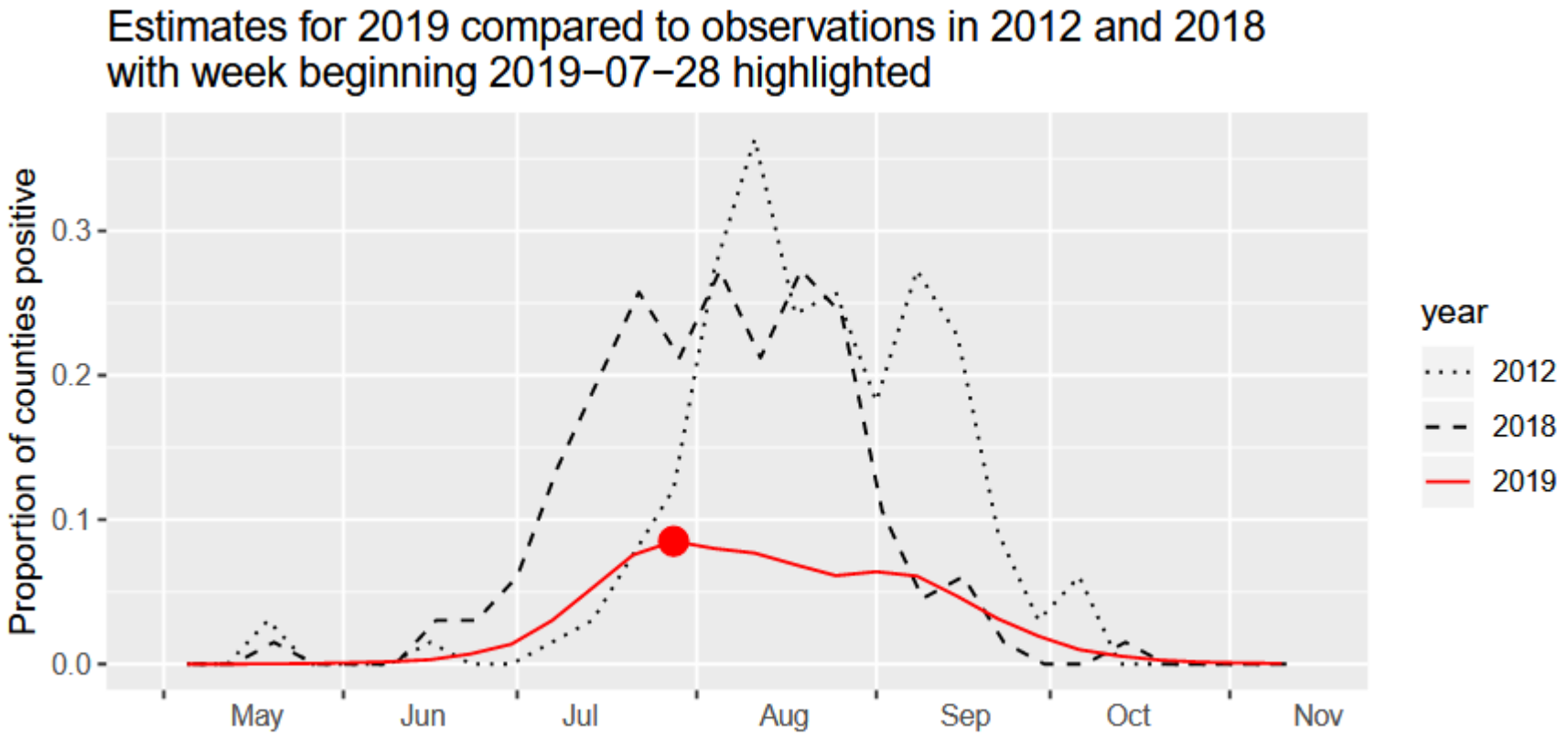
- Vector control divisions of county and city public health offices are charged with managing mosquito populations.
- They typically spray for mosquitos either when they receive a lot of complaints about the mosquito nuisance or when they have positive test results from their test sites where traps are deployed.
- Modeling complex local environmental dynamics may enable vector control to be more effective:
  - Container models such as WHATCH'EM could highlight local areas and moments of greater risk.
  - Seasonal-scale predictions could help manage resources given the severity of the mosquito season.
  - Regional-national mosquito distribution models could alert vector control to possible new invasive species.

SD WNV PREDICTIONS

South Dakota has an operational WNV Prediction System

- Vapor pressure and temperature are factored into state-wide models of WNV cases.





Report content from: http://mosquito.sdstate.edu/

RIFT VALLEY FEVER EMERGING HEALTH RISK NOTIFICATION

This Notification is a pilot effort of an interagency working group that integrates Federal expertise to synthesize risk information and response options for biological threats to US citizens and interests. The Notification is provided to USG operational biosurveillance centers for analysis and dissemination.

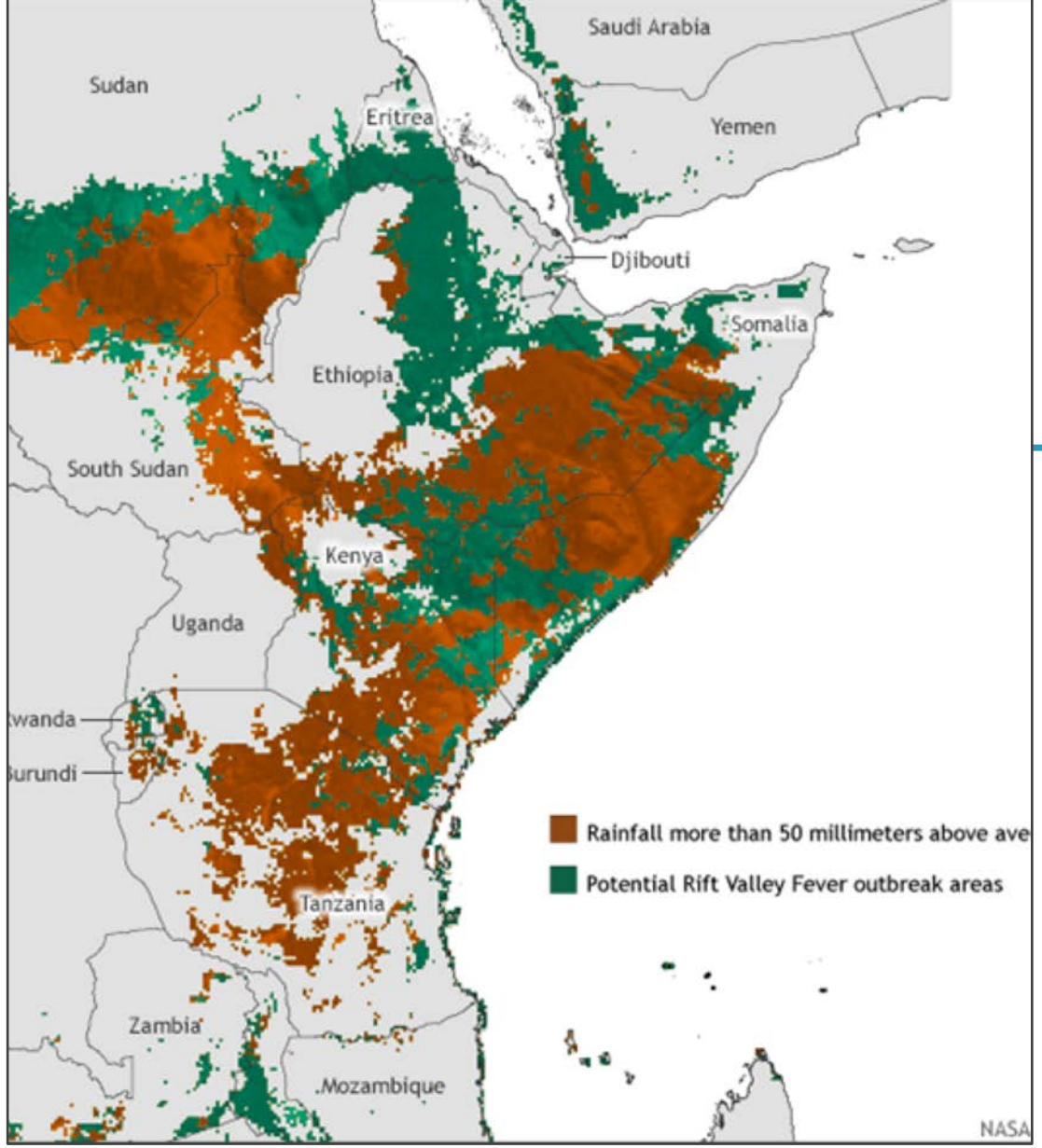
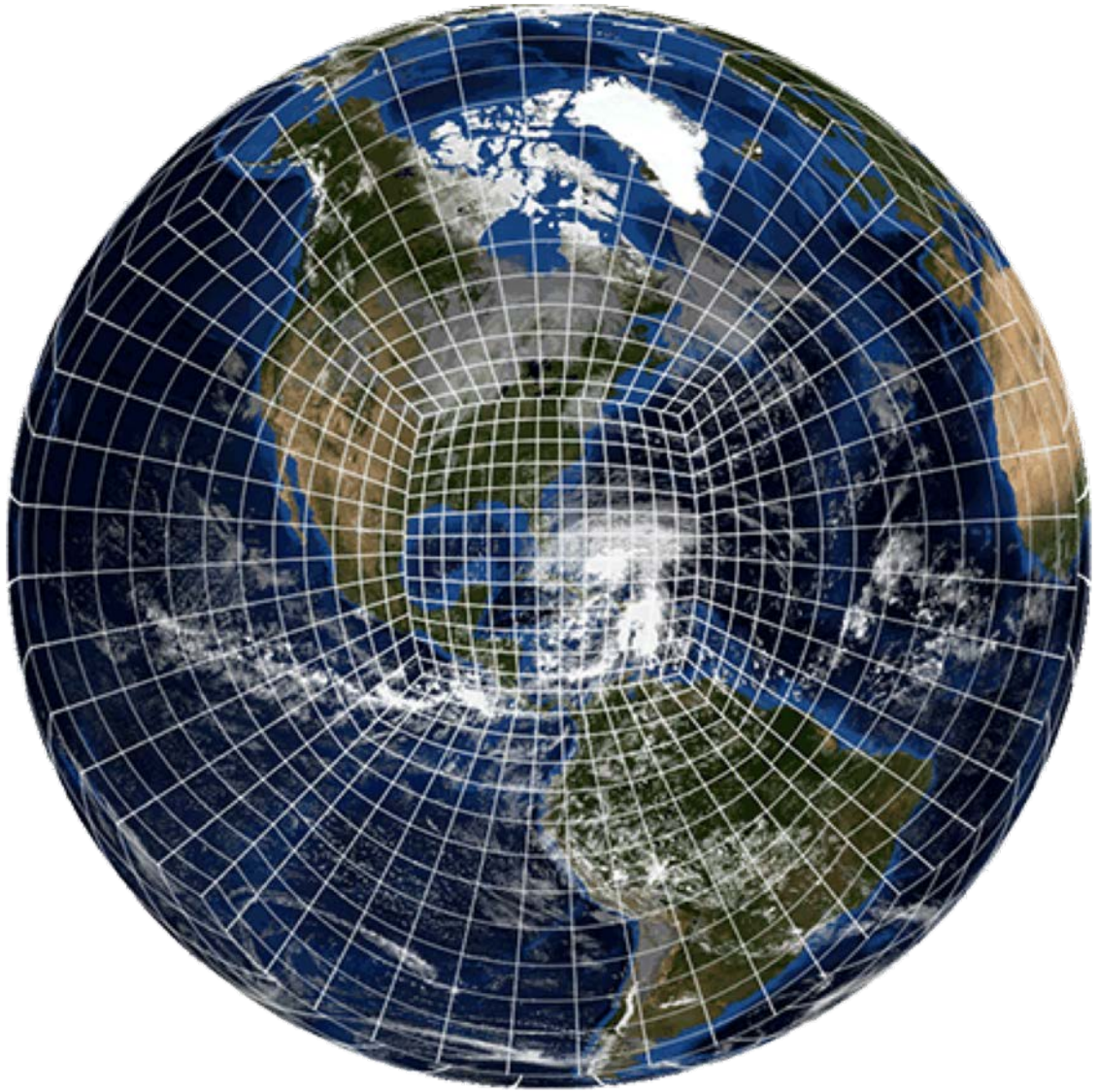


Fig 2. Rainfall RVF hotspots in east Africa, 1 Oct-16 Dec 2015.
Dark green: Potential epizootic areas (areas with previous known or predicted presence of RVF virus). Dark red: Potential epizootic areas with recent heavy rainfall. These are current RVF risk areas. *NASA/GSFC/GIMMS, USDA/ARS/CMAVE.*

https://www.climate.gov/news-features/understanding-climate/el-ni%C3%B1o-east-africa-and-rift-valley-fever



NOAA's **FV3: Finite-Volume Cubed-Sphere Dynamical Core** - from GFDL

NEXT STEPS

- USCLIVAR workshop to bring these modeling communities together to identify shared research needs/goals and opportunities for experimental operationalization.
- Follow research funding opportunities:
  - Belmont Forum Climate, Environment and Health Call
  - NOAA IRAP Projects on Decision Support Research on Climate-Sensitive Health Risks
  - NASA ROSES Earth Observations for Health
- USGCRP Report on Predicting Climate Sensitive Infectious Diseases to Protect Public Health and Strengthen National Security

https://www.gfdl.noaa.gov/fv3/

THANK YOU

hunter.jones@noaa.gov

https://climate.noaa.gov