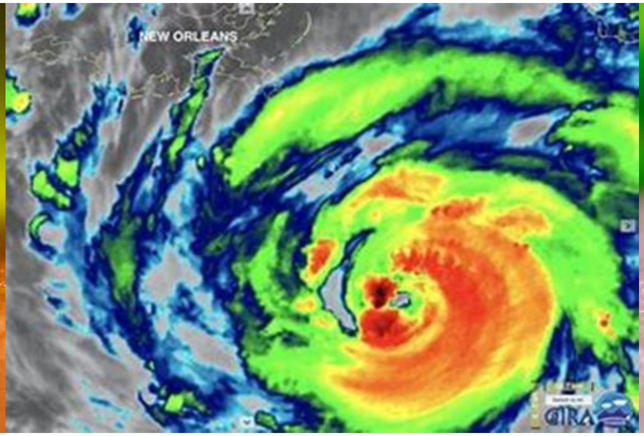
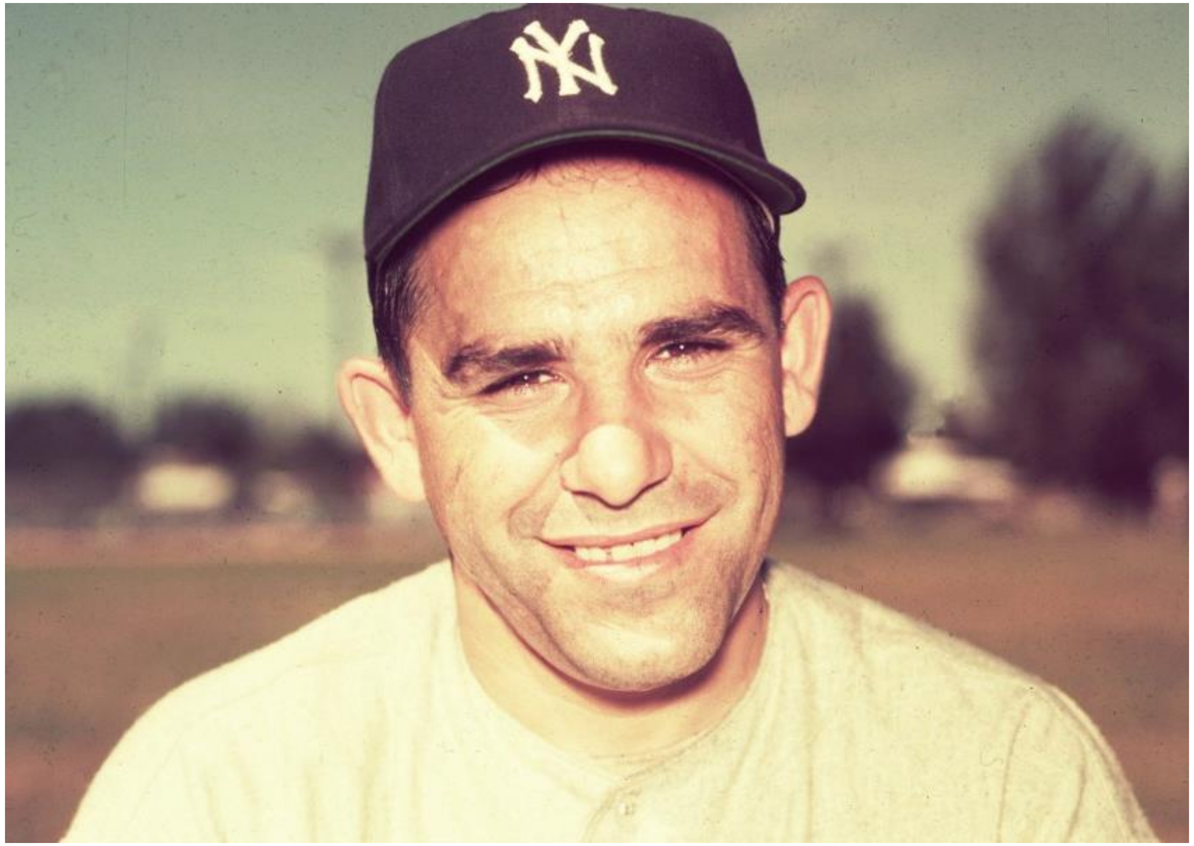
The Future of Mosquito Control in the Face of a Changing Climate

C. Ben Beard, MS, Ph.D.
Principal Deputy Director
Division of Vector-Borne Diseases, NCEZID, CDC
And
Co-Chair, CDC Task Force on Climate & Health

Not my choice of titles!



Yogi Berra

“The future ain’t what it used to be.”

“It's hard to make predictions, especially about the future.”

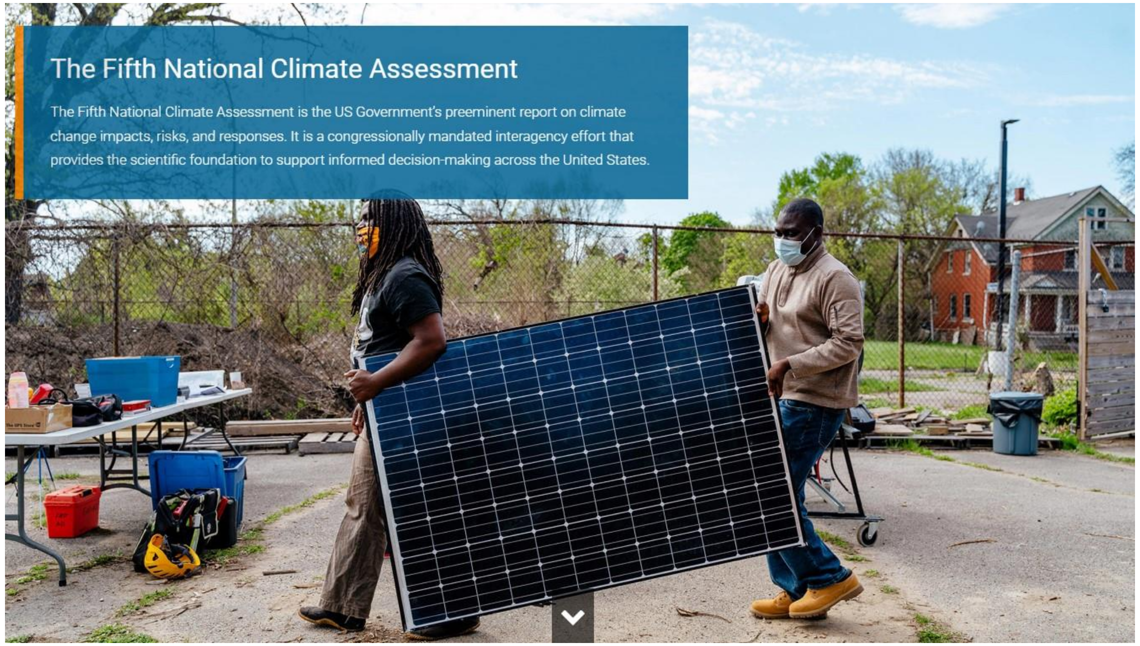
Outline

- Climate change observations and projections
- Climate effects on infectious diseases
- Vector-borne (VBD) burden and trends
- VBD drivers of emergence
- Promising developments

Climate change observations and projections

5th National Climate Assessment

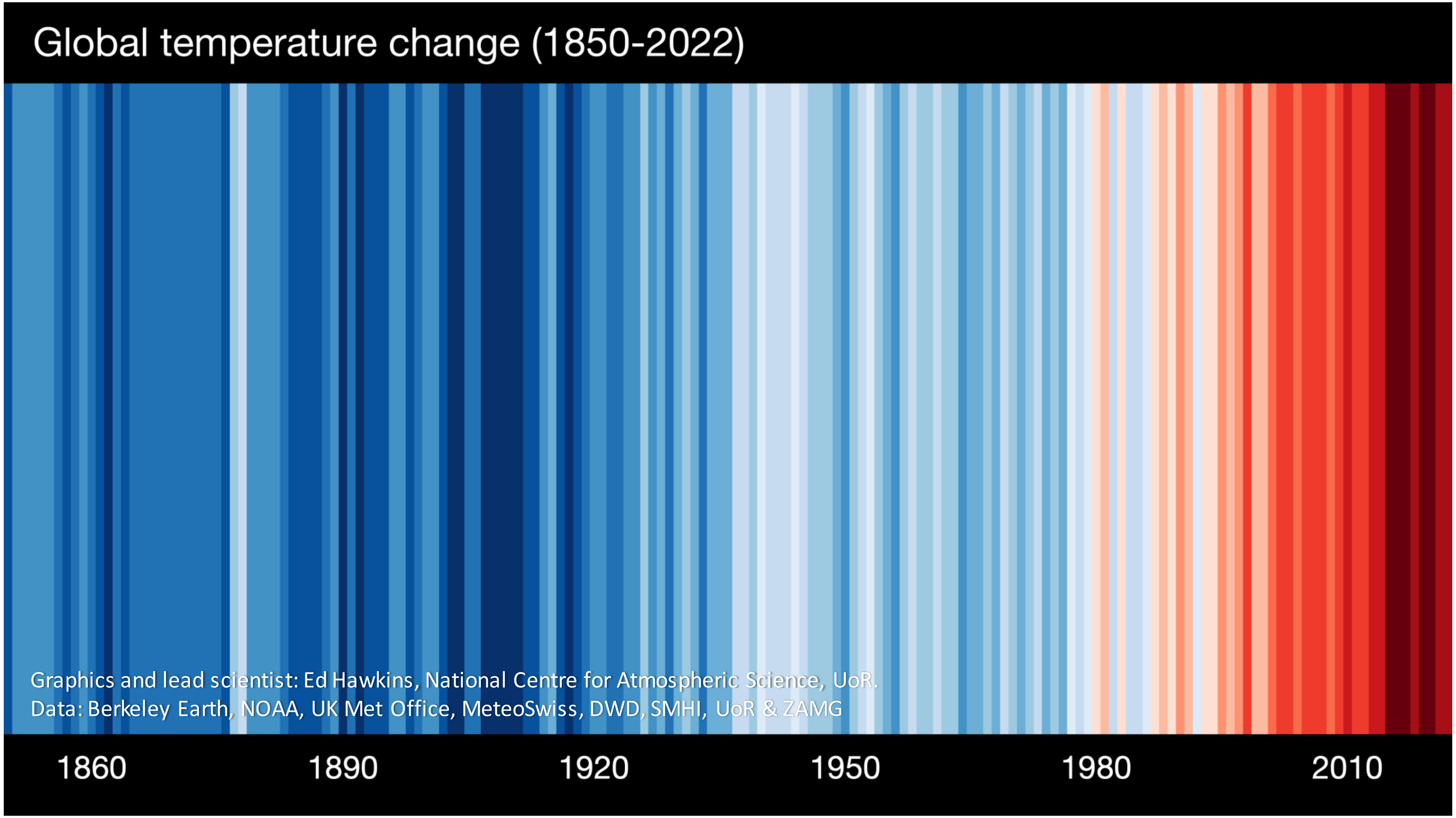
Climate Change Is Harming Human Health

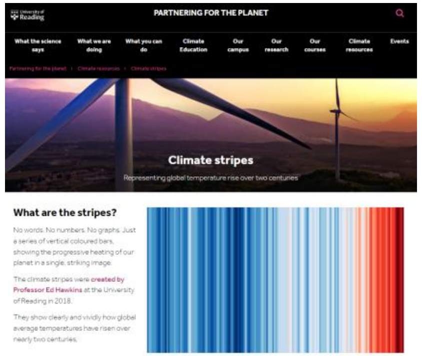


It is an established fact that climate change is harming physical, mental, spiritual, and community health and well-being through the increasing frequency and intensity of extreme events, increasing cases of infectious and vector-borne diseases, and declines in food and water quality and security. Climate-related hazards will continue to grow, increasing morbidity and mortality across all regions of the US (**very likely, very high confidence**).

USGCRP, 2023. https://nca2023.globalchange.gov/chapter/15

Global warming trends





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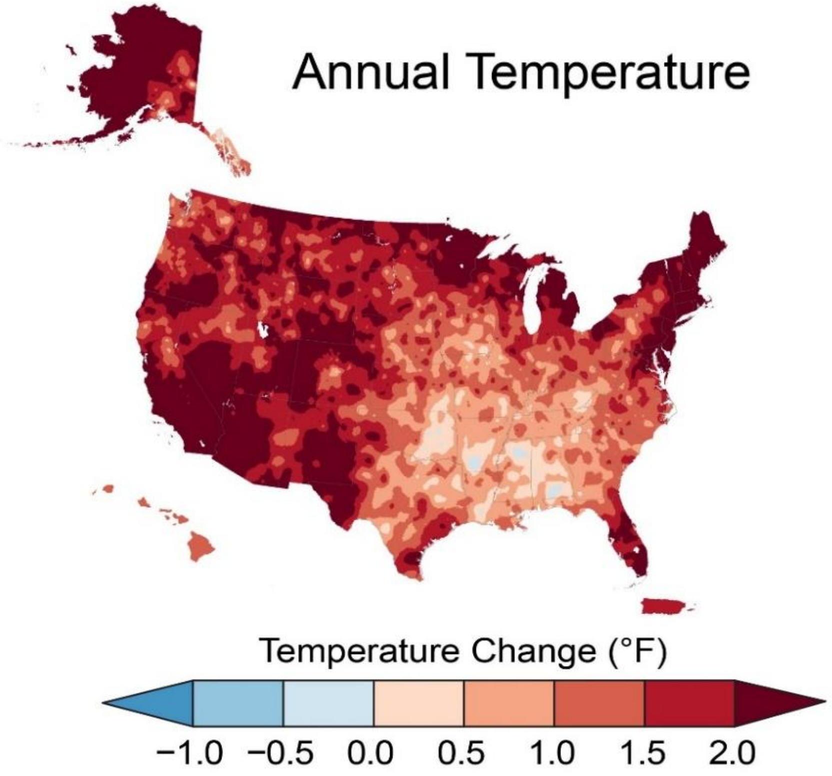
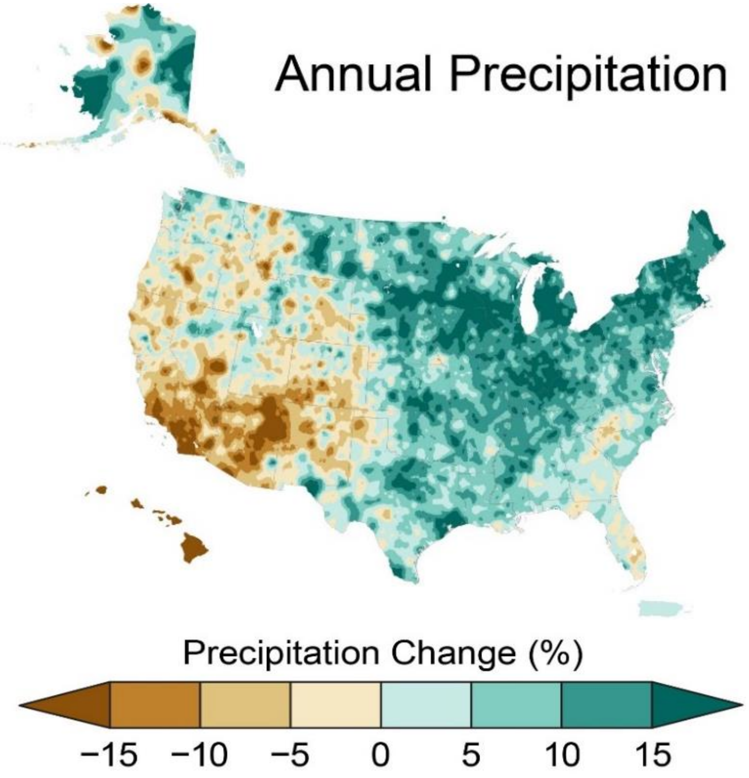
Each stripe represents the average temperature for a single year, relative to the average temperature over the period as a whole. Shades of blue indicate cooler-than-average years, while red shows years that were hotter than average. The stark band of deep red stripes on the right-hand side of the graphic show the rapid heating of our planet in recent decades.

Source: https://www.reading.ac.uk/planet/climate-resources/climate-stripes

Changes in annual temperature and precipitation 2002 – 2021 compared to 1901 – 1960





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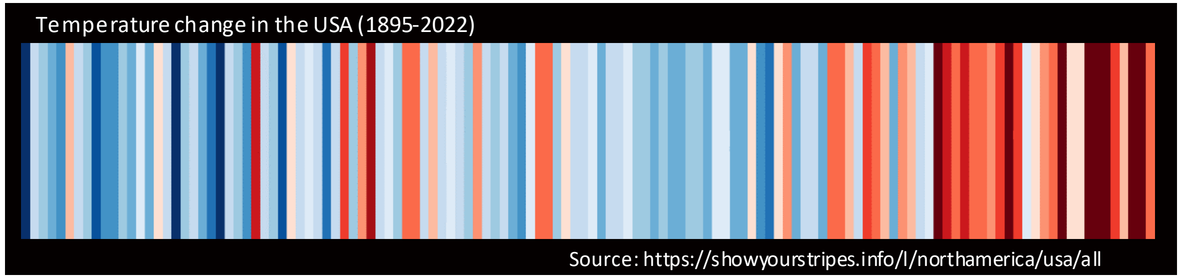
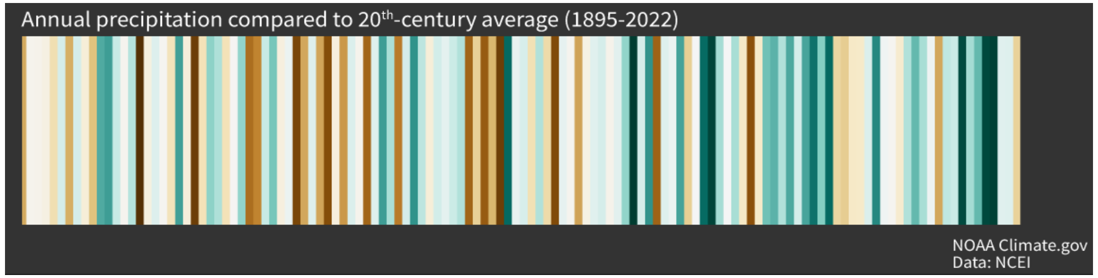
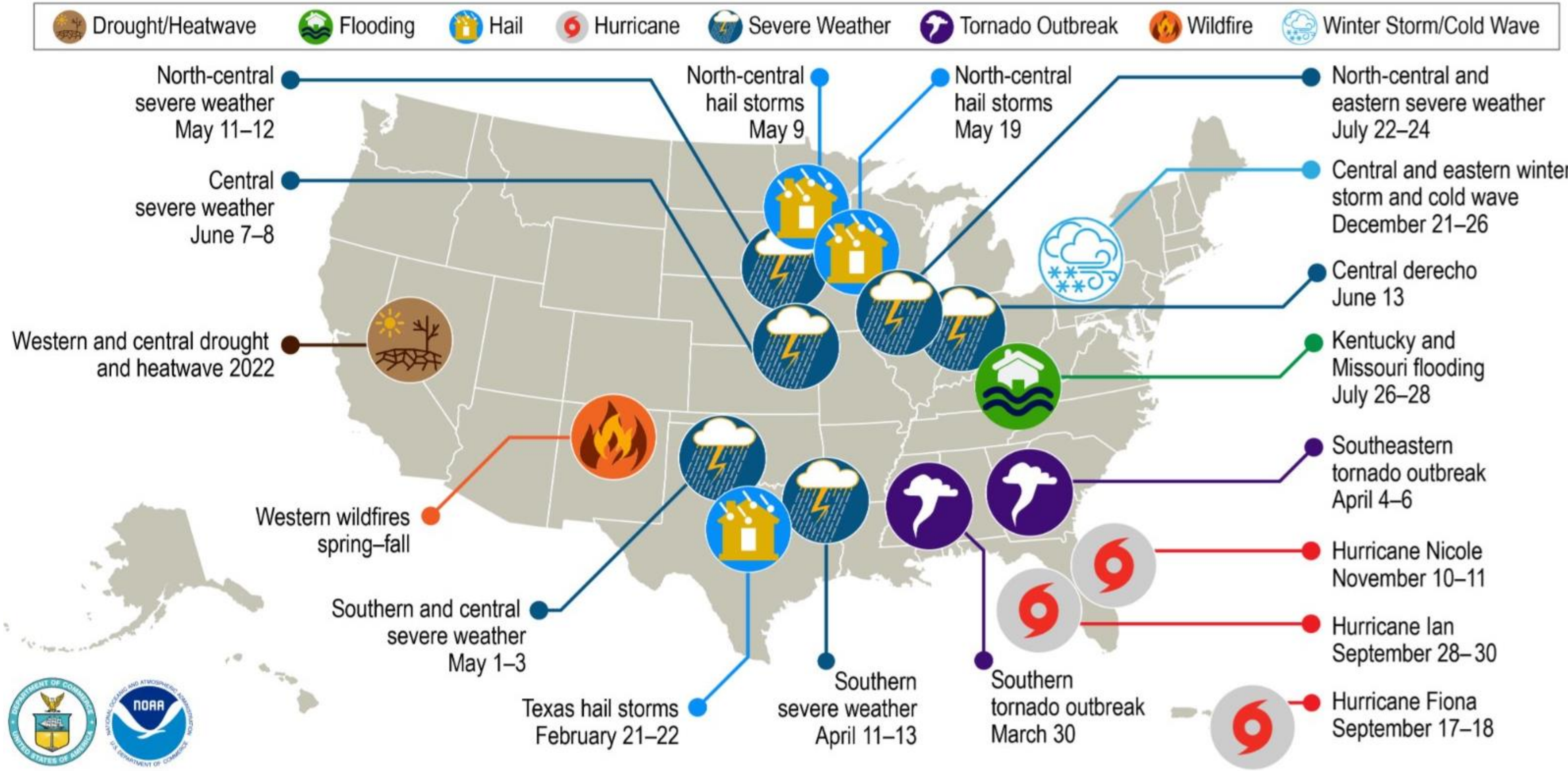
Source: https://nca2023.globalchange.gov/chapter/2/#fig-2-4





Billion-dollar weather and climate disasters in the U.S., 2022

5th National Climate Assessment

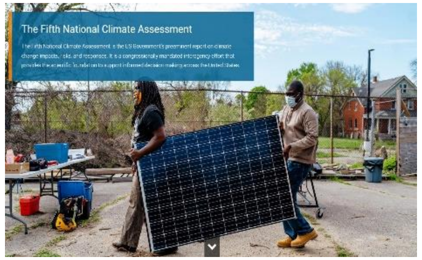


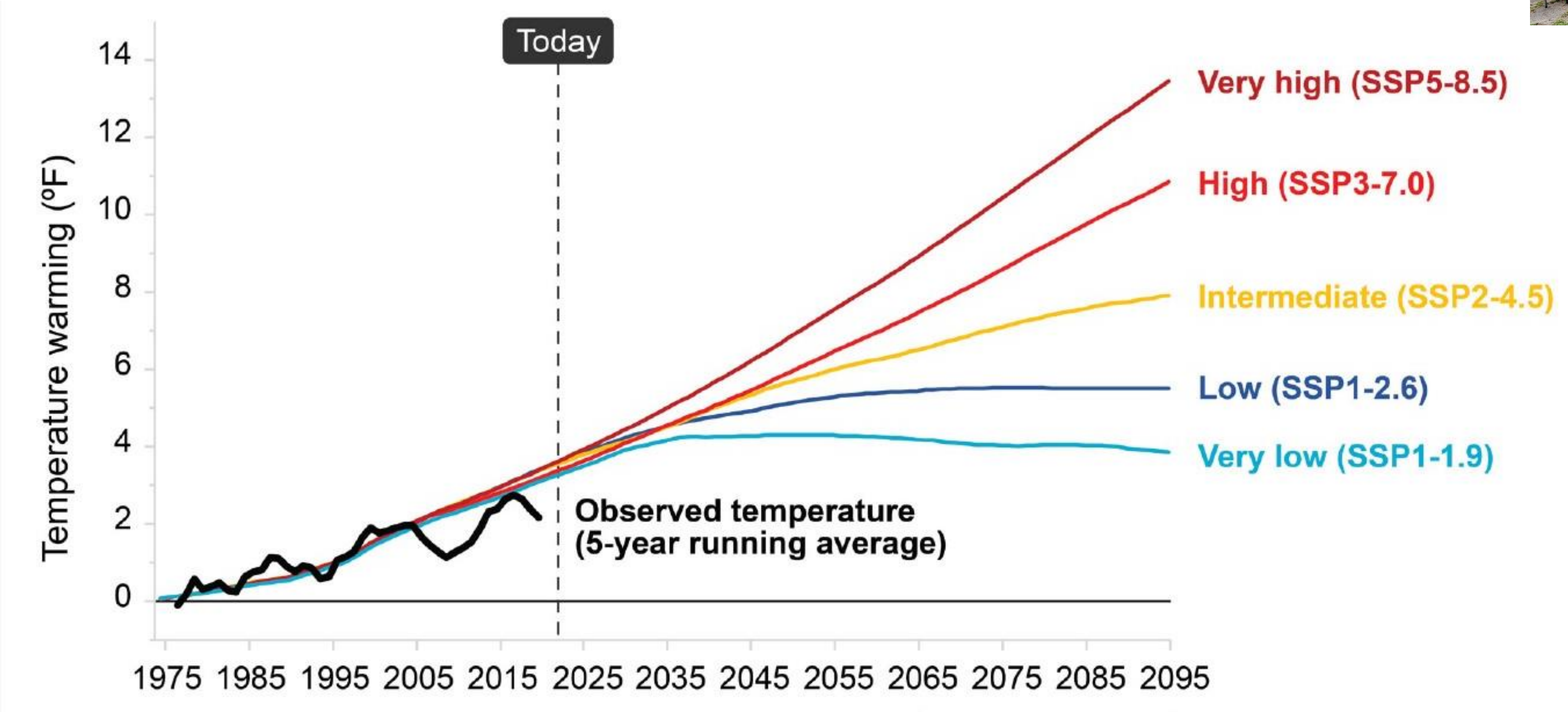
*This map denotes the approximate location for each of the **18 separate billion-dollar weather and climate disasters that impacted the United States in 2022.***

Source: USGCRP, 2023. https://nca2023.globalchange.gov/chapter/15

Future Warming in the United States will depend on the total amount of global greenhouse gas emissions

5th National Climate Assessment

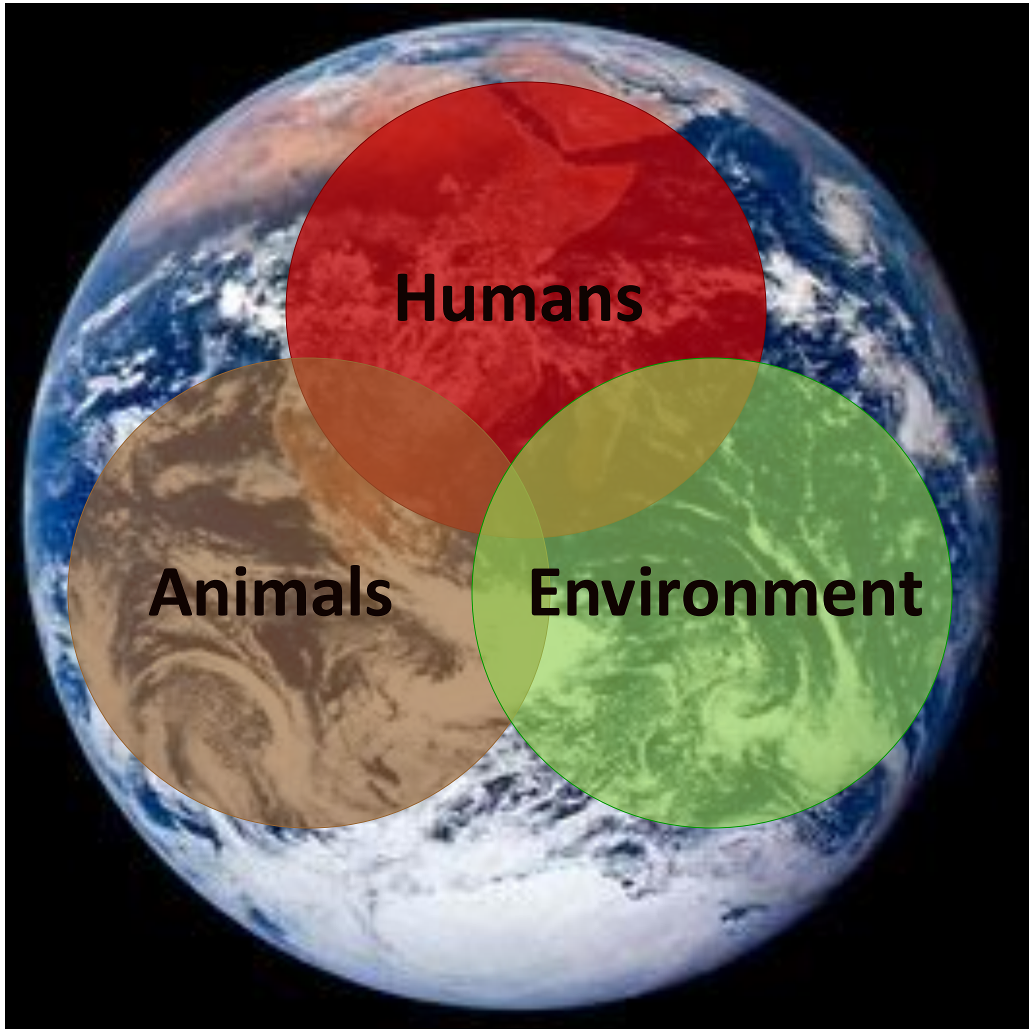




Source: USGCRP, 2023. https://nca2023.globalchange.gov/chapter/15

Climate effects on infectious diseases

Climate change and emerging infectious diseases through a *One Health* lens



Climate strongly influences the distribution and occurrence of environmentally-sensitive diseases. Changes in climate lead to changes in the environment, which result in changes in the ecology, incidence and distribution of these diseases.

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

5th National Climate Assessment

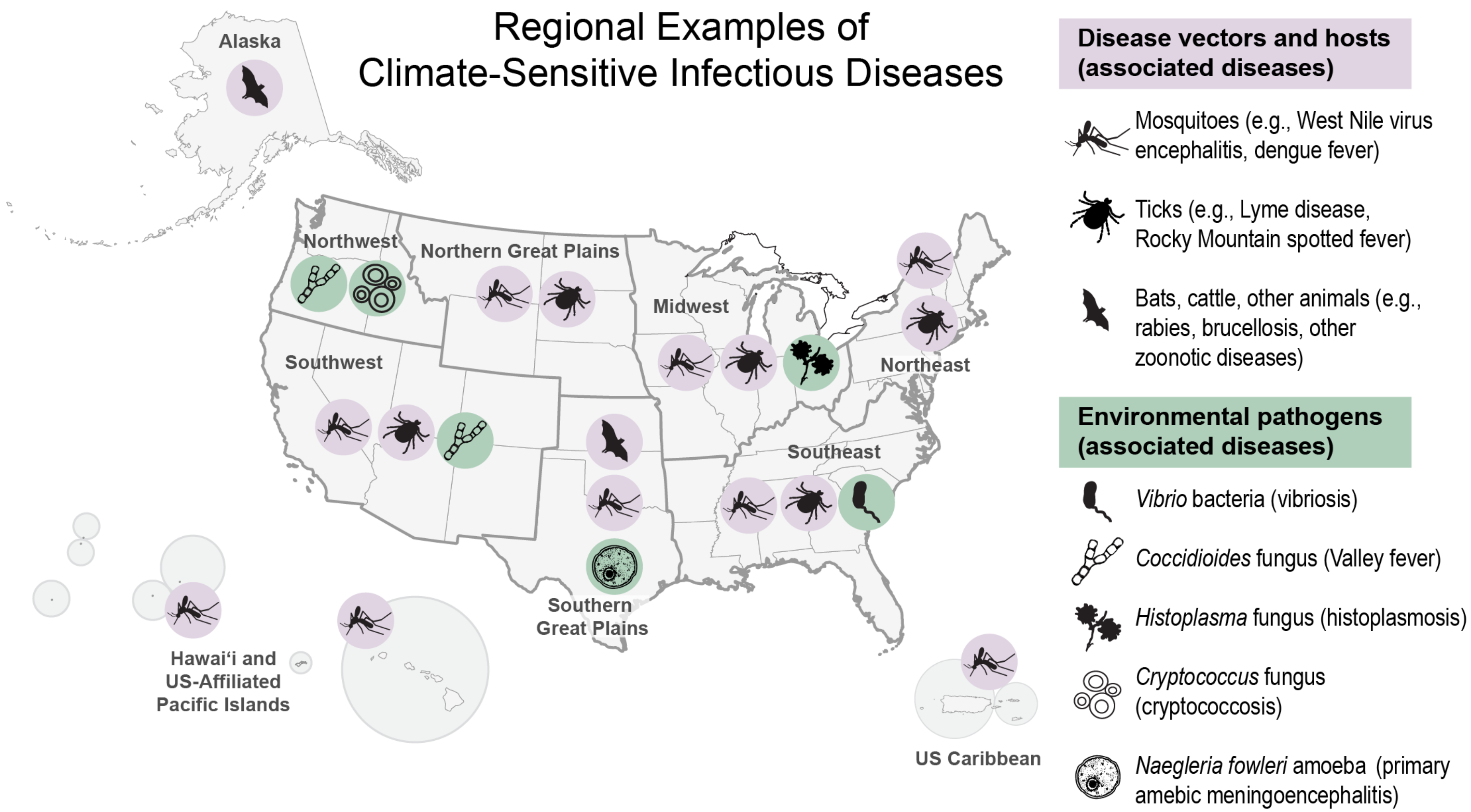
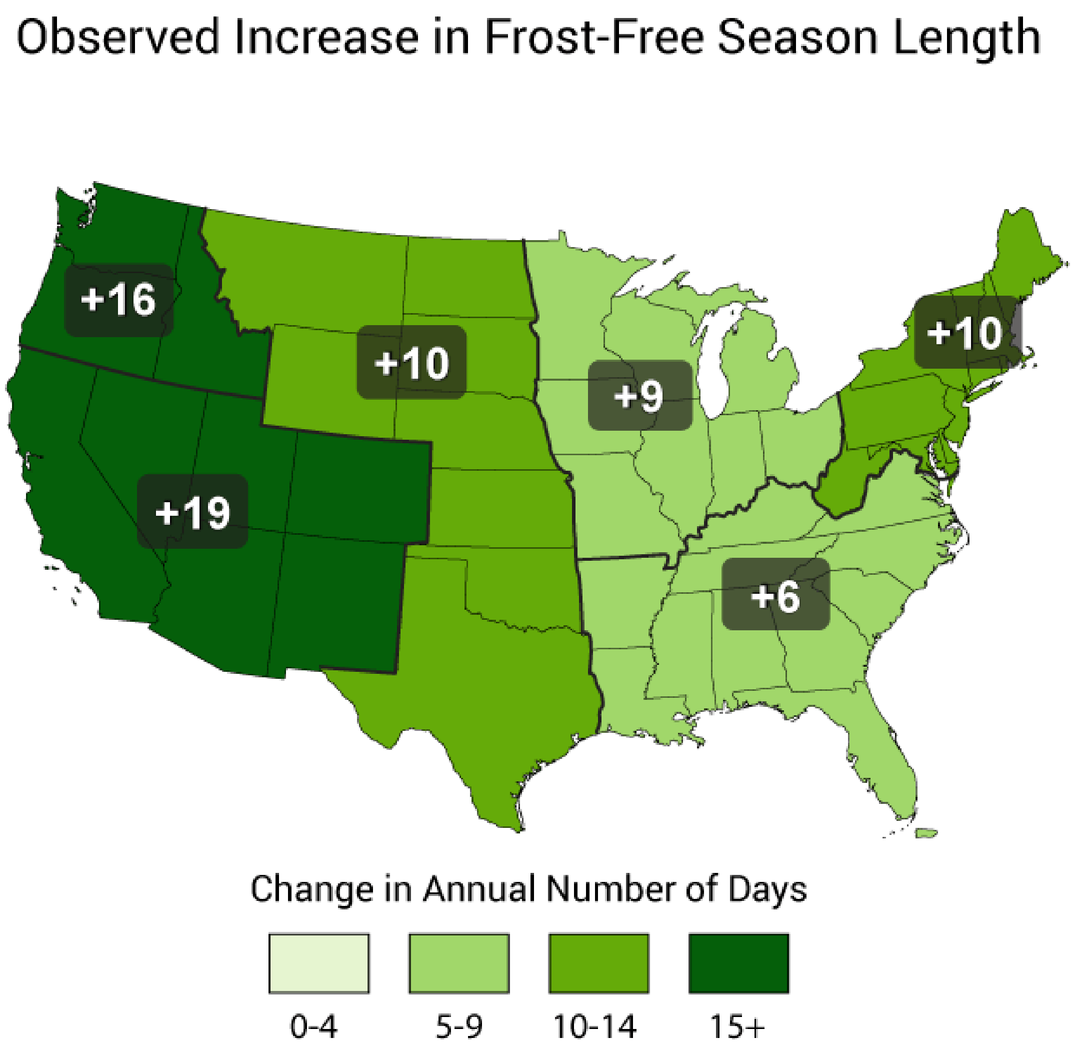


Figure 15.2: The map shows select examples of regional climate-sensitive infectious diseases, based on recent changes in geographic range or incidence. Some regions will experience increases in tick- and mosquito-borne diseases, zoonotic diseases, and pathogens, both in geographic area and extended seasonality. Figure credit: Los Alamos National Laboratory, CDC, Columbia University, University of Arizona, and University of Colorado. **Source: USGCRP, 2023. https://nca2023.globalchange.gov/chapter/15**

Influence of climate change on seasonal weather

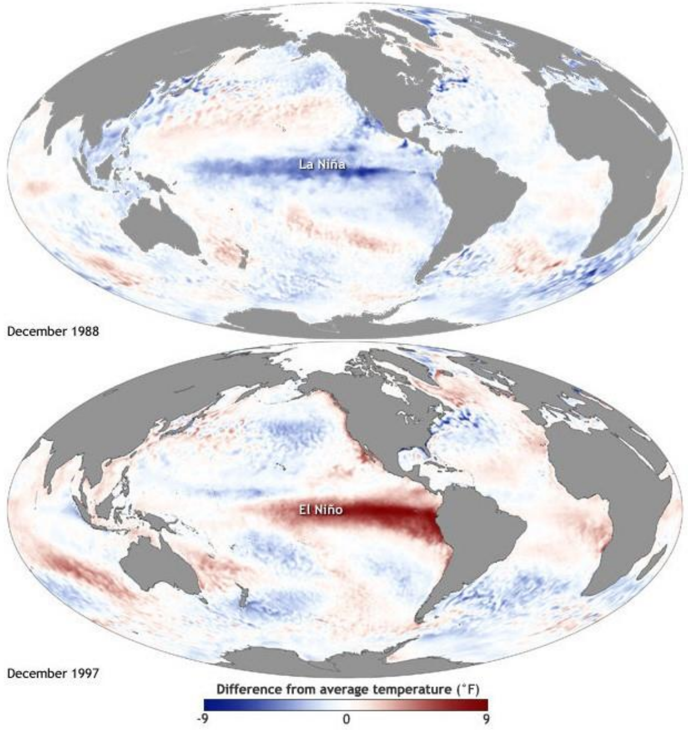
- Longer and warmer summers
- Shorter and milder winters
- Fewer frost days
- Increased frequency of severe and unpredictable weather events (e.g., storms, heat waves, droughts)
- Regional variations



Source: 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).

Climate Change and El Niño

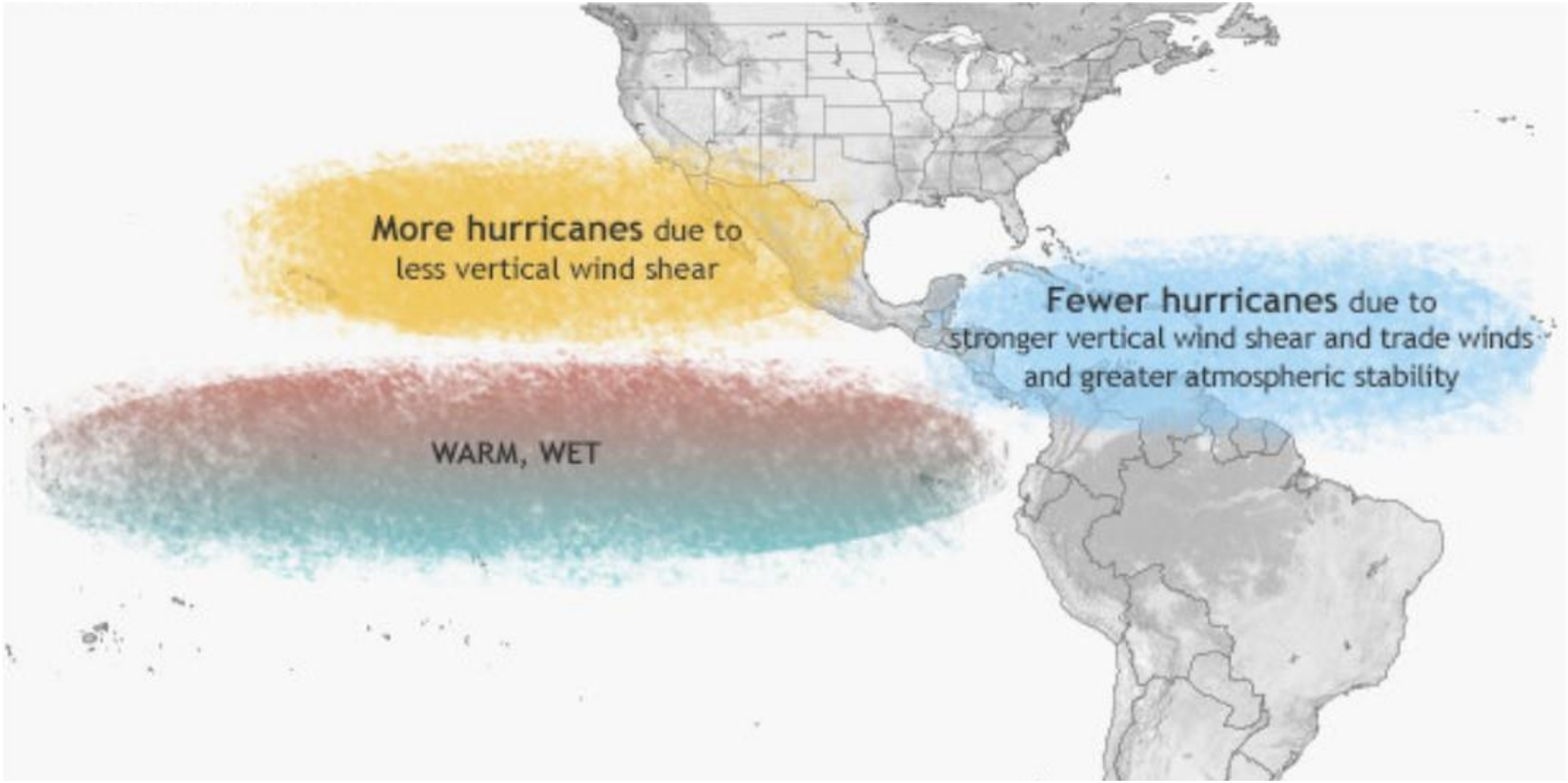
- El Niño-Southern Oscillation (ENSO) refers to the warm and cool phases of a recurring climate pattern across the tropical Pacific (El Niño = warming; La Niña = cooling)
- Lead to changes in precipitation and temperature patterns across many regions of the world
- Probability of hurricanes in the Caribbean, Gulf of Mexico, and Atlantic Ocean is greater in La Niña years
- El Niño not caused by climate change, but may be intensified
- El Niño events have been linked to increases in vector-borne diseases such as Rift Valley Fever in Kenya and dengue in South America, due to increased rainfall and the subsequent impact on mosquito populations



https://www.climate.gov/enso

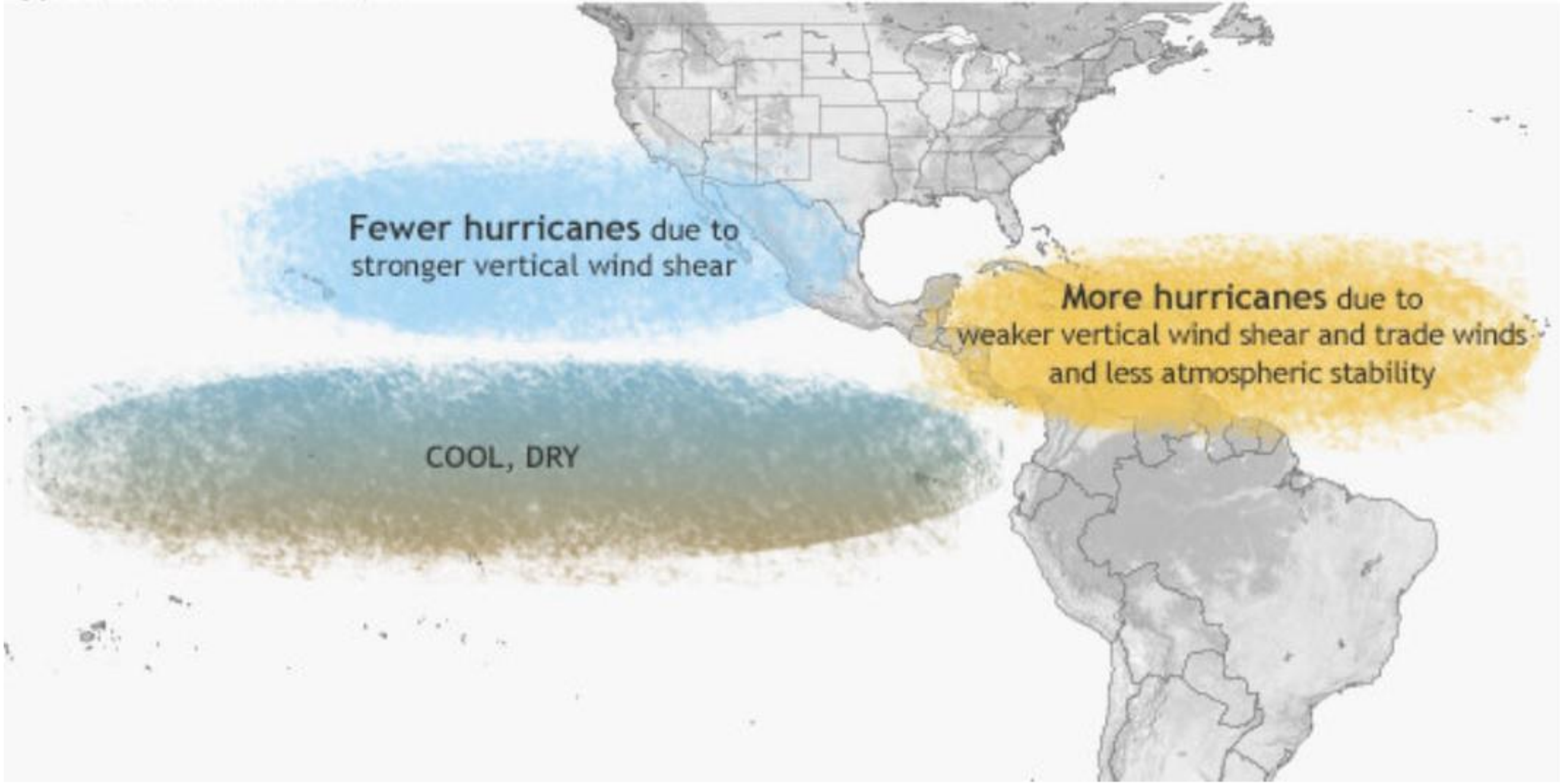
NOAA Forecast (11 April 2024): Transition from El Niño to ENSO-neutral likely by April-June (85% chance), with odds of La Niña developing by June-August (60%).

Typical El Niño influence



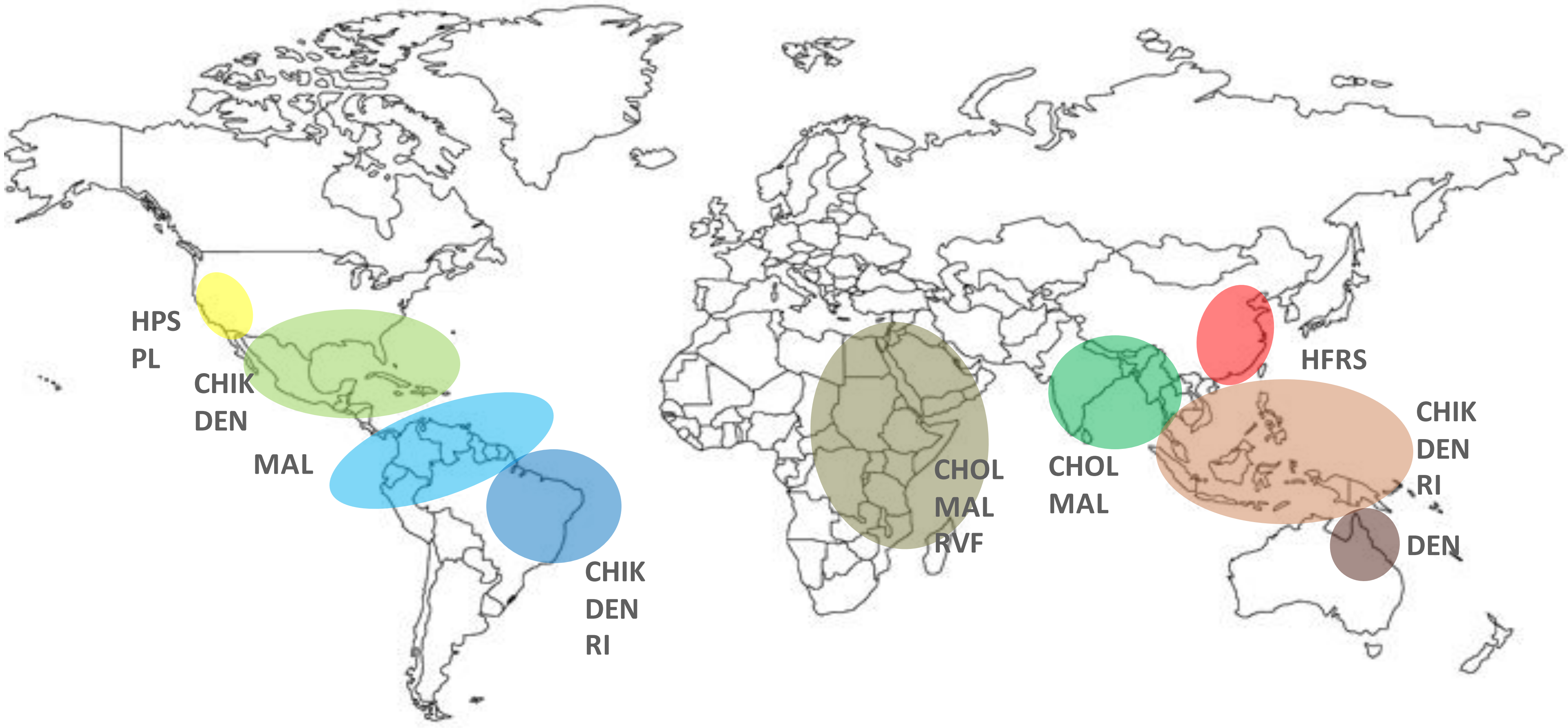
https://www.climate.gov/news-features/blogs/enso/impacts-el-ni%C3%B1o-and-la-ni%C3%B1a-hurricane-season

Typical La Niña influence



https://www.climate.gov/news-features/blogs/enso/impacts-el-ni%C3%B1o-and-la-ni%C3%B1a-hurricane-season

Climate, weather, and Infectious Diseases:
Potential Elevated Risks Associated with ENSO



KEY

CHIK Chikungunya
CHOL Cholera
DEN Dengue
HFRS Hemorrhagic fever with renal syndrome
HPS Hantavirus Pulmonary Syndrome
MAL Malaria
PL Plague
RVF Rift Valley Fever
RI Respiratory illness

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.

VBD burden and trends

2023 – A busy year in vector-borne diseases!

CNN health

What to know about dengue as cases are reported in Florida

SCIENCE

NATIONAL GEOGRAPHIC

Why tick-borne diseases have reached 'epidemic proportions'

TIME

HEALTH • DISEASE

How Climate Change Affects the Spread of Lyme Disease

STAT Reporting from the frontiers of health and medicine

HEALTH

Cases of alpha-gal syndrome caused by tick bites on the rise, CDC reports

In a Decaying Queens Fortress, It's One Man Versus 47 Kinds of Mosquito

Dr. Waheed Bajwa and the Health Department's Office of Vector Surveillance and Control work all year to protect New York City from a summertime West Nile virus outbreak.

The Daily

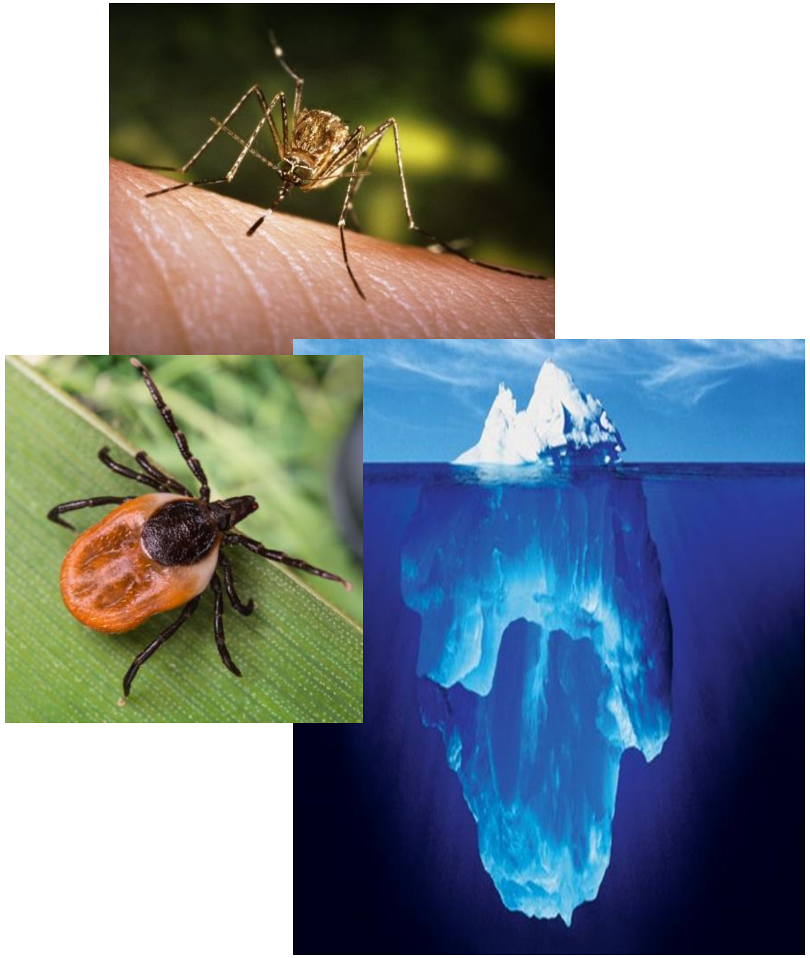
The Mosquitoes Are Winning

CNN + Follow

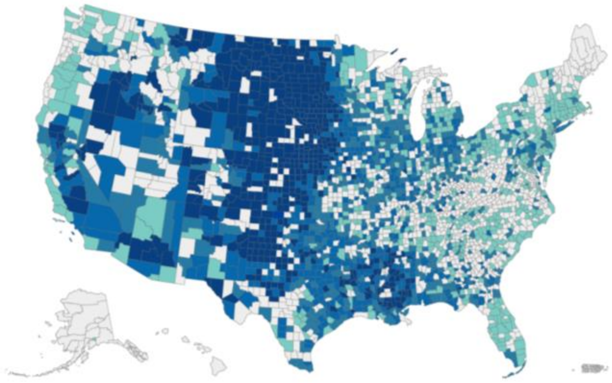
Locally acquired malaria case reported in Arkansas

Trends in VBDs in the U.S.

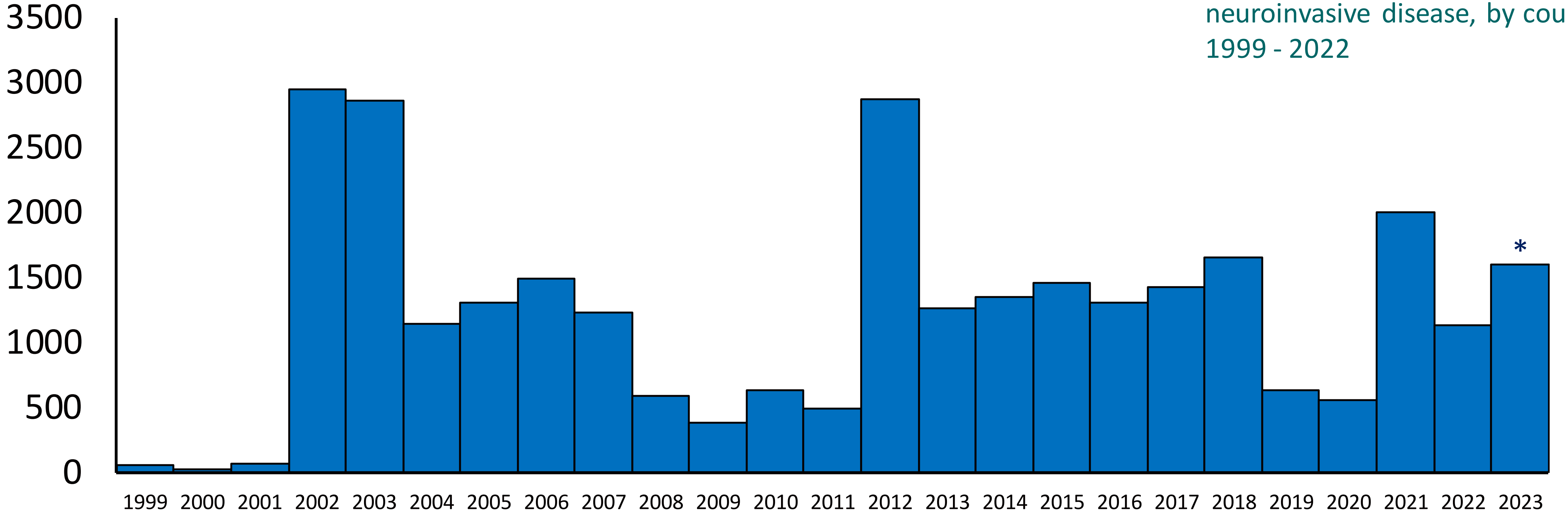
- Between 2003 and 2023, more than 1 million cases of VBDs were reported in the U.S.
- The number of annual reported cases approximately doubled over this period.
- Reported cases substantially underestimate actual disease occurrence (ex. Lyme disease: ~476,000 diagnosed and treated cases/year).
- Tickborne diseases (TBDs) account for over 80% of all reported VBD cases.
- Local outbreaks of imported VBDs are occurring more frequently.



West Nile virus neuroinvasive disease cases reported to CDC, 1999 – 2023



Annual incidence of WNV neuroinvasive disease, by country, 1999 - 2022



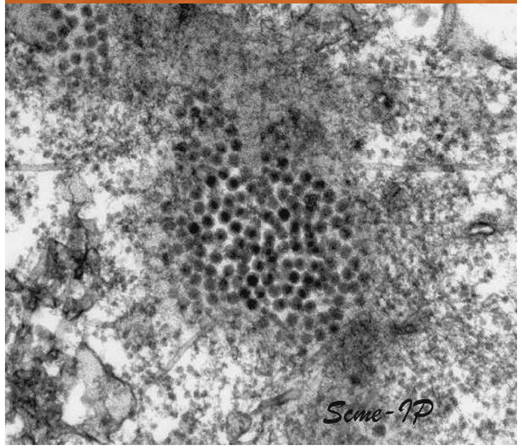
* 1,599 provisional neuroinvasive disease cases reported as of February 23, 2024

Source: https://www.cdc.gov/westnile/statsmaps/finalmapsdata/index.html

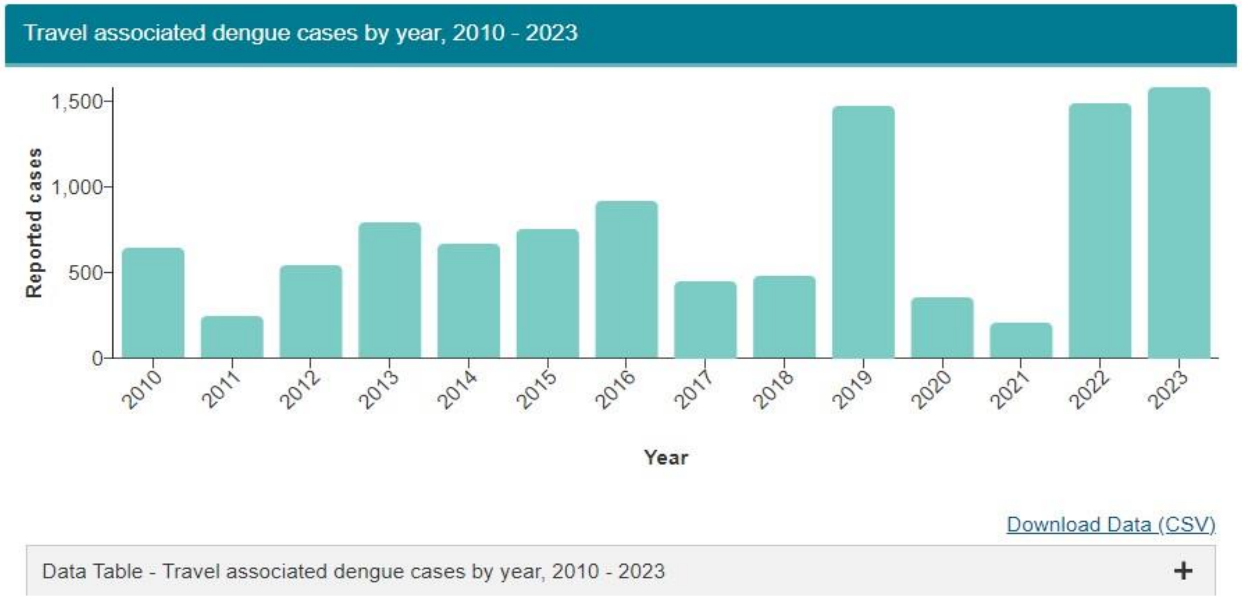
West Nile virus outbreak, Arizona, 2021

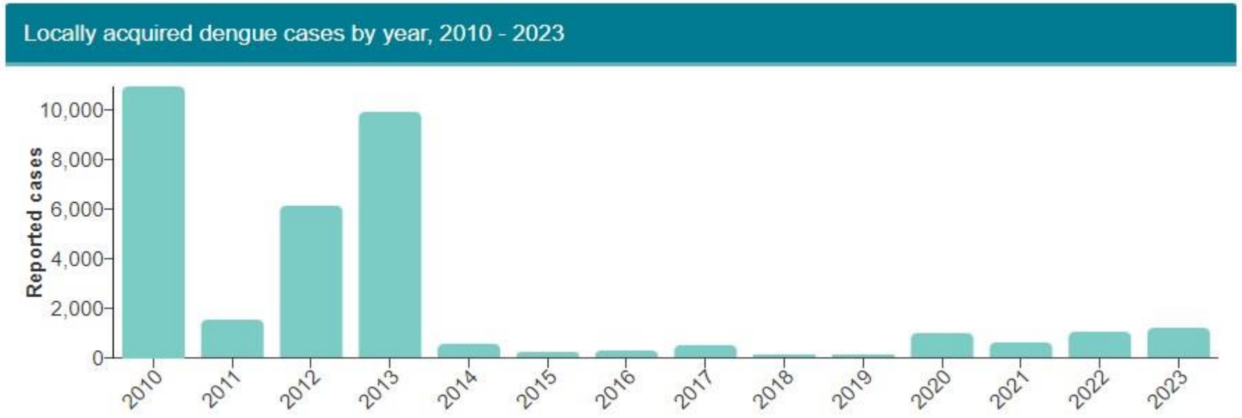
- Largest local outbreak in U.S. since WNV introduction in 1999
- 2,911 total cases and 227 deaths reported nationwide
- Approximately 59% of all cases occurred in Arizona
  - 1,710 cases with 127 deaths
  - 86% of cases occurred in Maricopa County (Phoenix)
  - Cases occurred into November

  [Source: https://www.azdhs.gov/documents/preparedness/epidemiology-disease-control/mosquito-borne/west-nile/data/west-nile-virus-stats-2021.pdf?v=20220111]
- Analyses suggest that a wetter than average monsoonal season, may have interacted with other factors in causing this outbreak

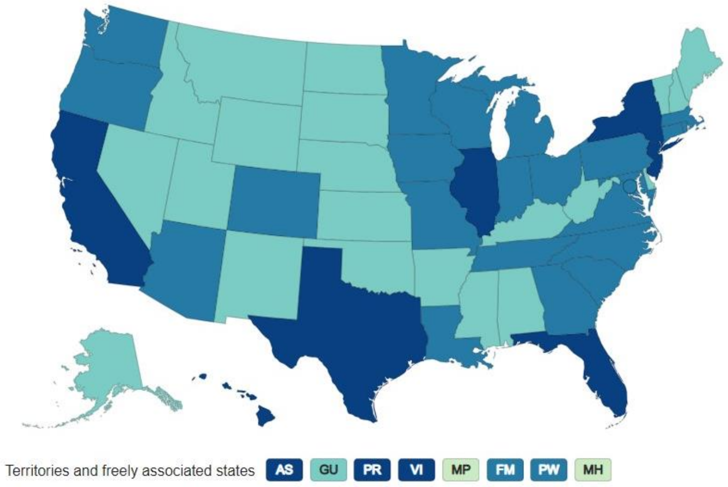


Dengue cases in the United States, 2010 – 2023





All dengue cases by jurisdiction of residence in US states and territories, 2010 - 2023

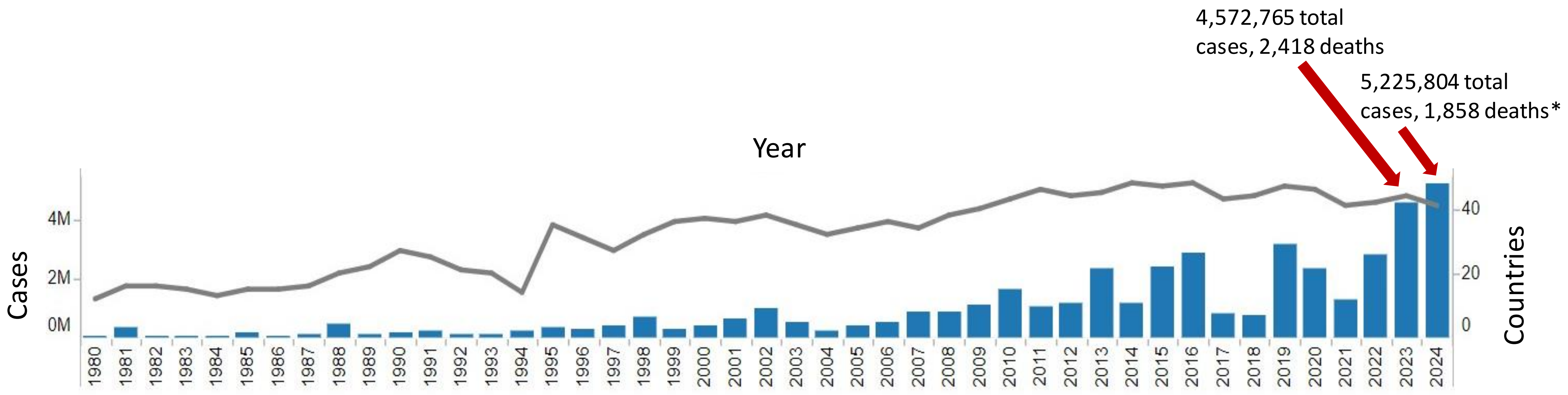


Locally acquired cases in the U.S., 2023

- Puerto Rico: 1,025
- Florida: 178
- California: 2
- Texas: 1

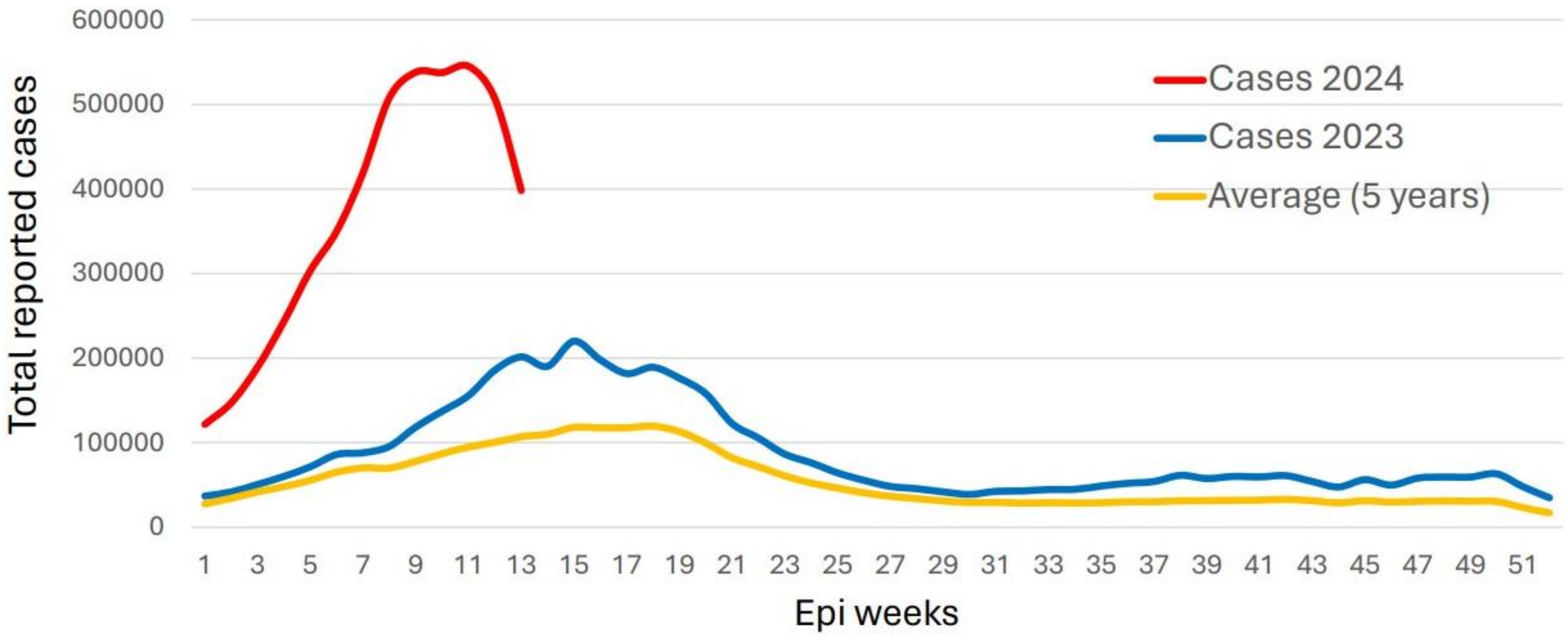
Source: https://www.cdc.gov/dengue/statistics-maps/historic-data.html

Dengue cases in the Americas, 1980 – 2024



Source: https://www3.paho.org/data/index.php/en/mnu-topics/indicadores-dengue-en.html
*Cases in 2024 as of 4/19/2024

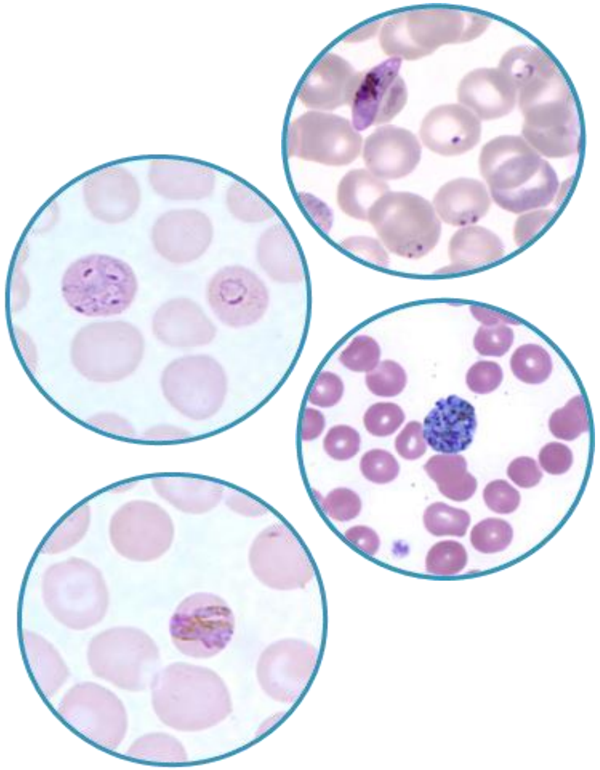
Suspected dengue cases in the Americas as of epi week 13 of 2024 compared to 2023 and the average of the last 5 years



Source: https://www.paho.org/en/topics/dengue

Locally acquired malaria in the United States, 2023

- Four unrelated, locally acquired malaria transmission events in four U.S. states – Florida [7] and Texas [1] during May – July 2023, Maryland [1] in August, and Arkansas [1] in October – all treated and recovered
- Previously documented locally acquired, mosquito-transmitted cases occurred in Palm Beach County, Florida, in July-August 2003
- *Anopheles* vectors competent for malaria transmission exist throughout the U.S. (32 states plus territories)*. Thus, there is ongoing risk that local transmission can occur
- Risk for local transmission of malaria in the U.S. is influenced primarily by imported cases



DPDx

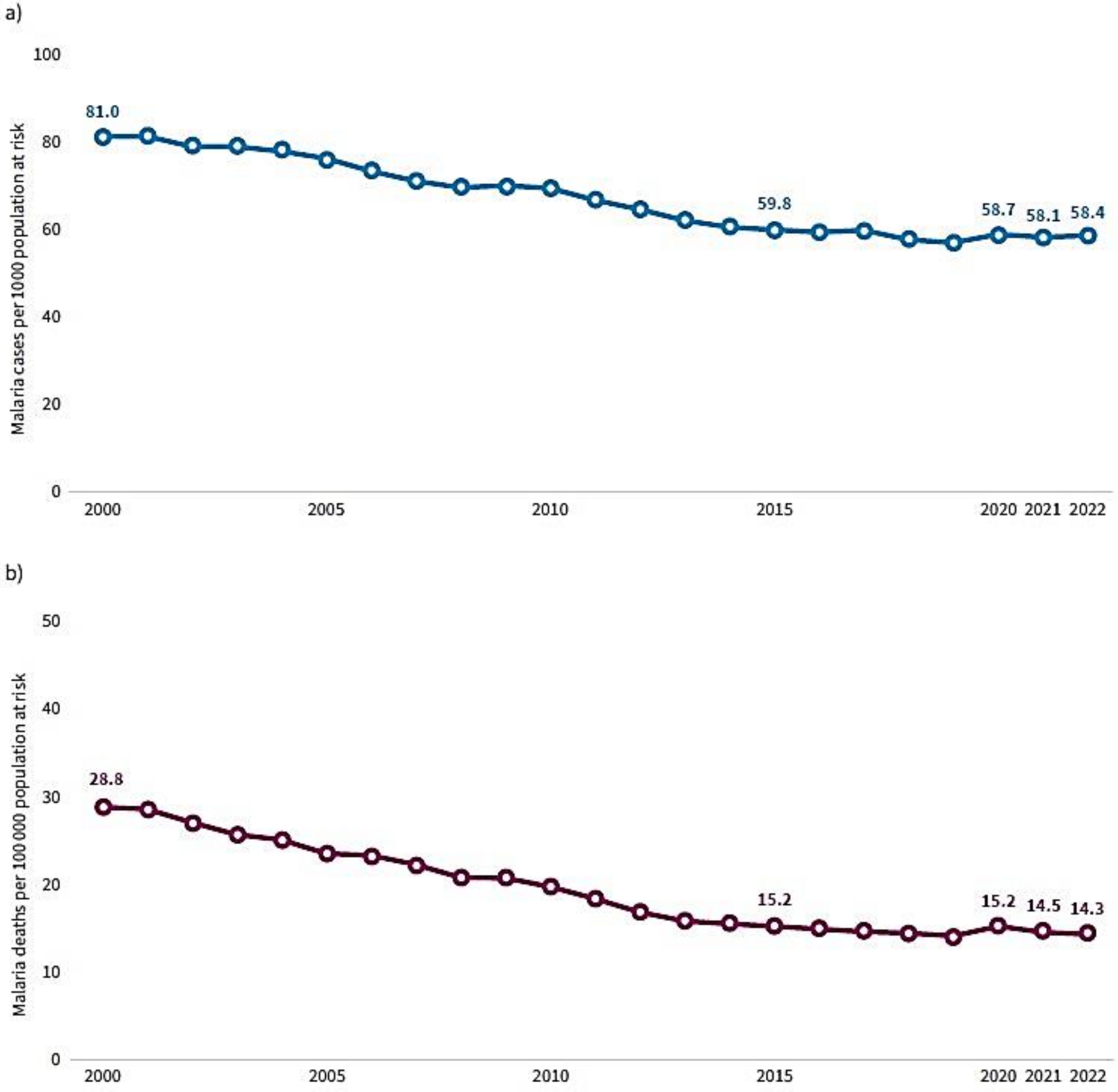
***Source:** Dye-Braumuller, K. C., & Kanyangarara, M. (2021). Malaria in the USA: how vulnerable are we to future outbreaks?. Current tropical medicine reports, 8, 43-51. https://doi.org/10.1007/s40475-020-00224-z

Global malaria, 2022

- 249 million estimated clinical cases occurred worldwide in 85 countries, with 608,000 deaths
- 29 countries accounted for 95% of all cases and 96% of all deaths
- Four countries accounted for over 50% of all deaths globally: DRC, Niger, and Tanzania
- Global progress in reduction of cases and deaths stalled in recent years likely due to COVID-related disruption in access to malaria prevention and case management tools

Fig. 3.3.

Global trends in a) malaria case incidence (cases per 1000 population at risk) and b) mortality rate (deaths per 100 000 population at risk), 2000–2022; and c) distribution of malaria cases and d) deaths by country, 2022
Source: WHO estimates.

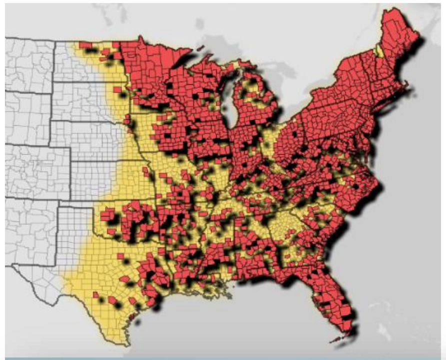


WHO: World Health Organization.

Source: World malaria report 2023. Geneva: World Health Organization; 2023. License: CC BY-NC-SA 3.0 IGO

VBD trends looking forward

- Americans are at an increasing risk for VBDs.
- Vaccines are limited, so prevention relies largely on actions aimed at reducing exposure to the bites of potentially infected vectors.
- Current trends will likely persist and even worsen in the absence of effective prevention tools and implementation capacity.
- The factors driving VBD emergence are complex and include the influence of multiple social and environmental factors.

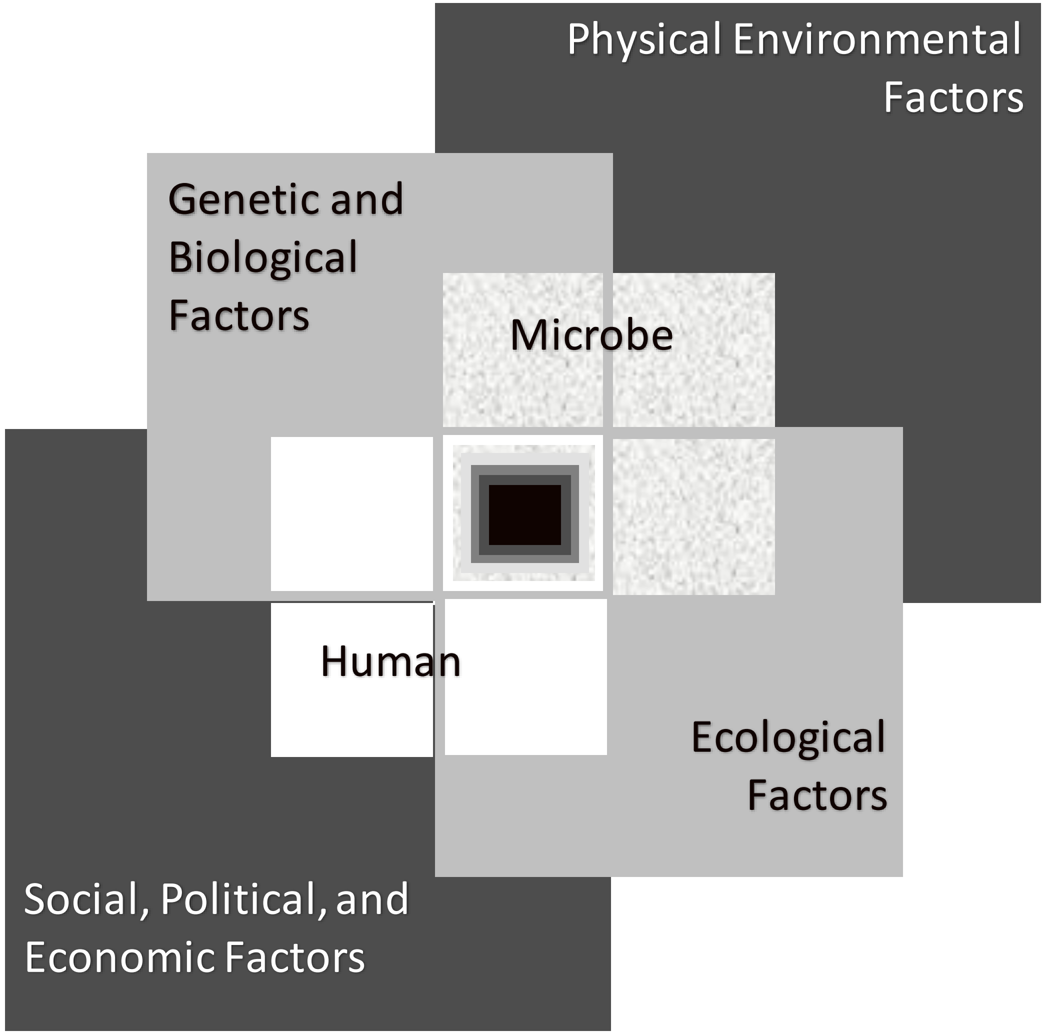



VBD drivers of emergence

Drivers for disease emergence

- 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

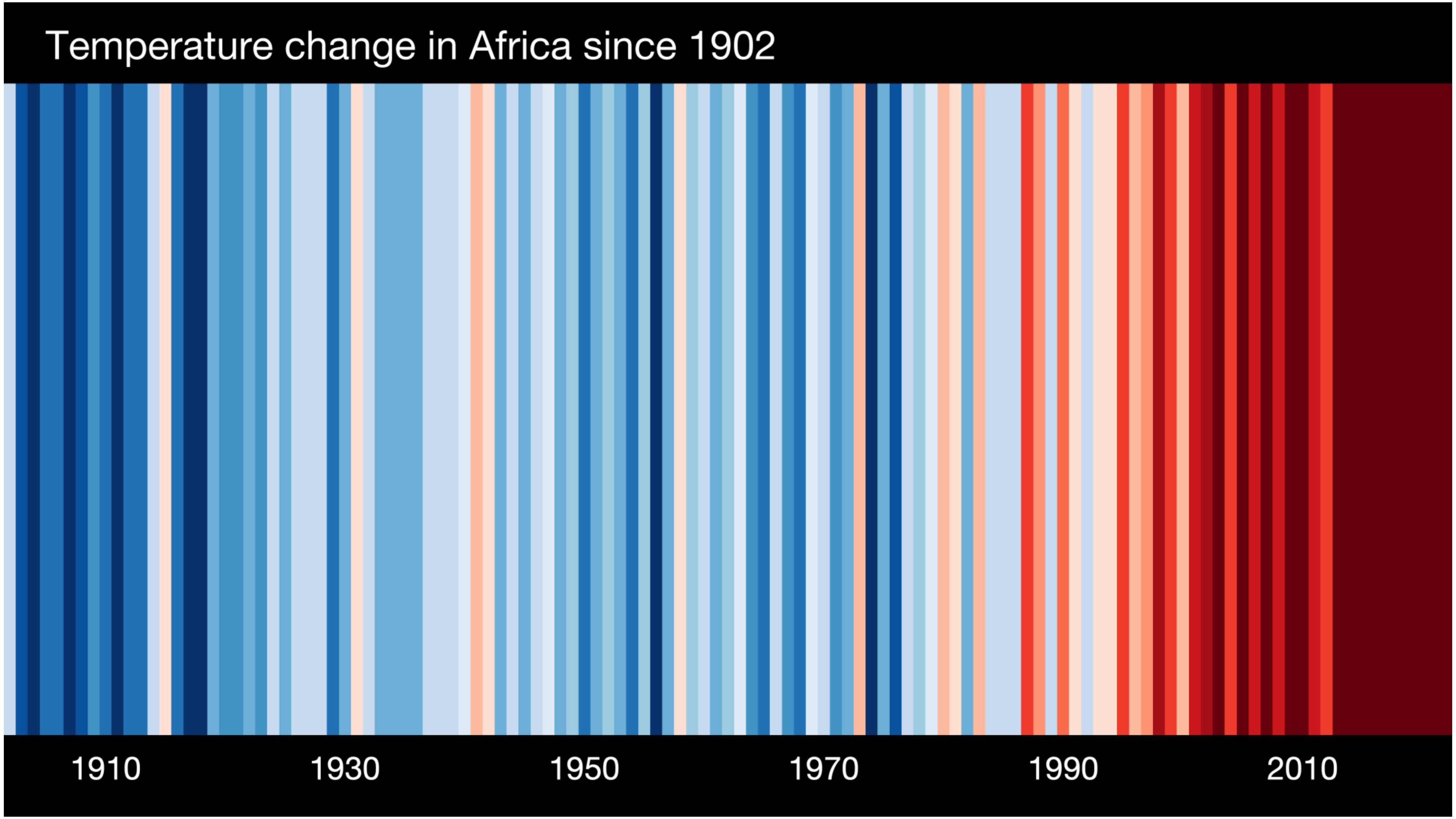
Note the challenge of attribution!



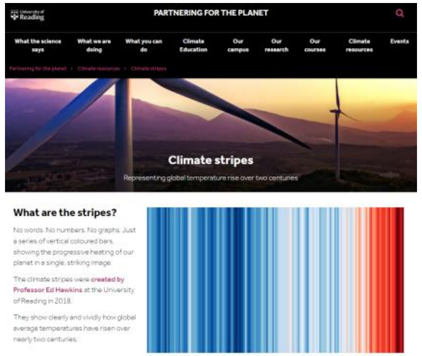
Convergence Model for Emerging Diseases

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

Global warming trends



Source: https://www.reading.ac.uk/planet/climate-resources/climate-stripes



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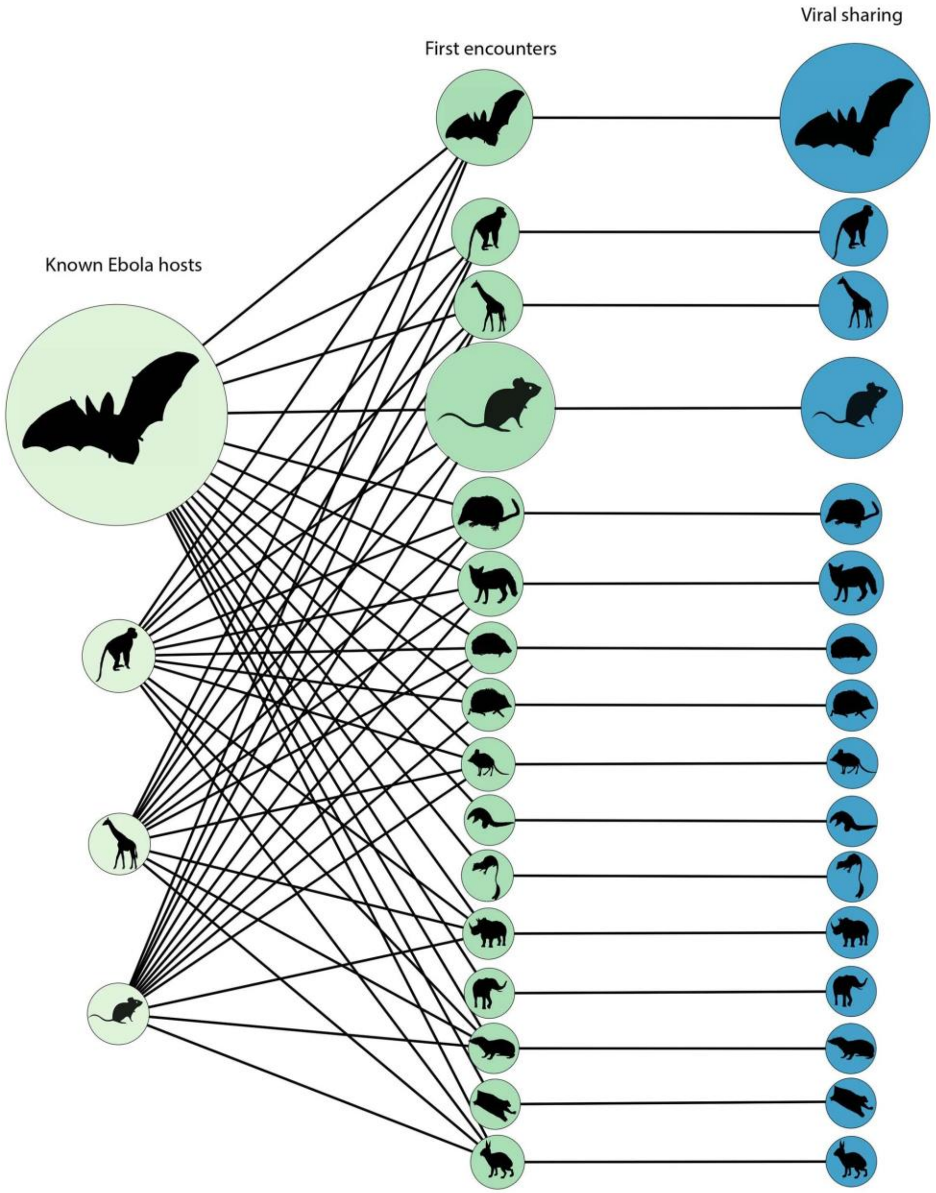
Each stripe represents the average temperature for a single year, relative to the average temperature over the period as a whole. Shades of blue indicate cooler-than-average years, while red shows years that were hotter than average. The stark band of deep red stripes on the right-hand side of the graphic show the rapid heating of our planet in recent decades.

Climate change: Key interconnecting issues of *global* importance…

- Environmental change leading to cross-species pathogen transmission and viral spillover
- Global migration due to forced population displacement
- Urban and peri-urban growth

Of Note: The burden of health impacts will be most significant in the Global South

Environmental change and cross-species viral transmission

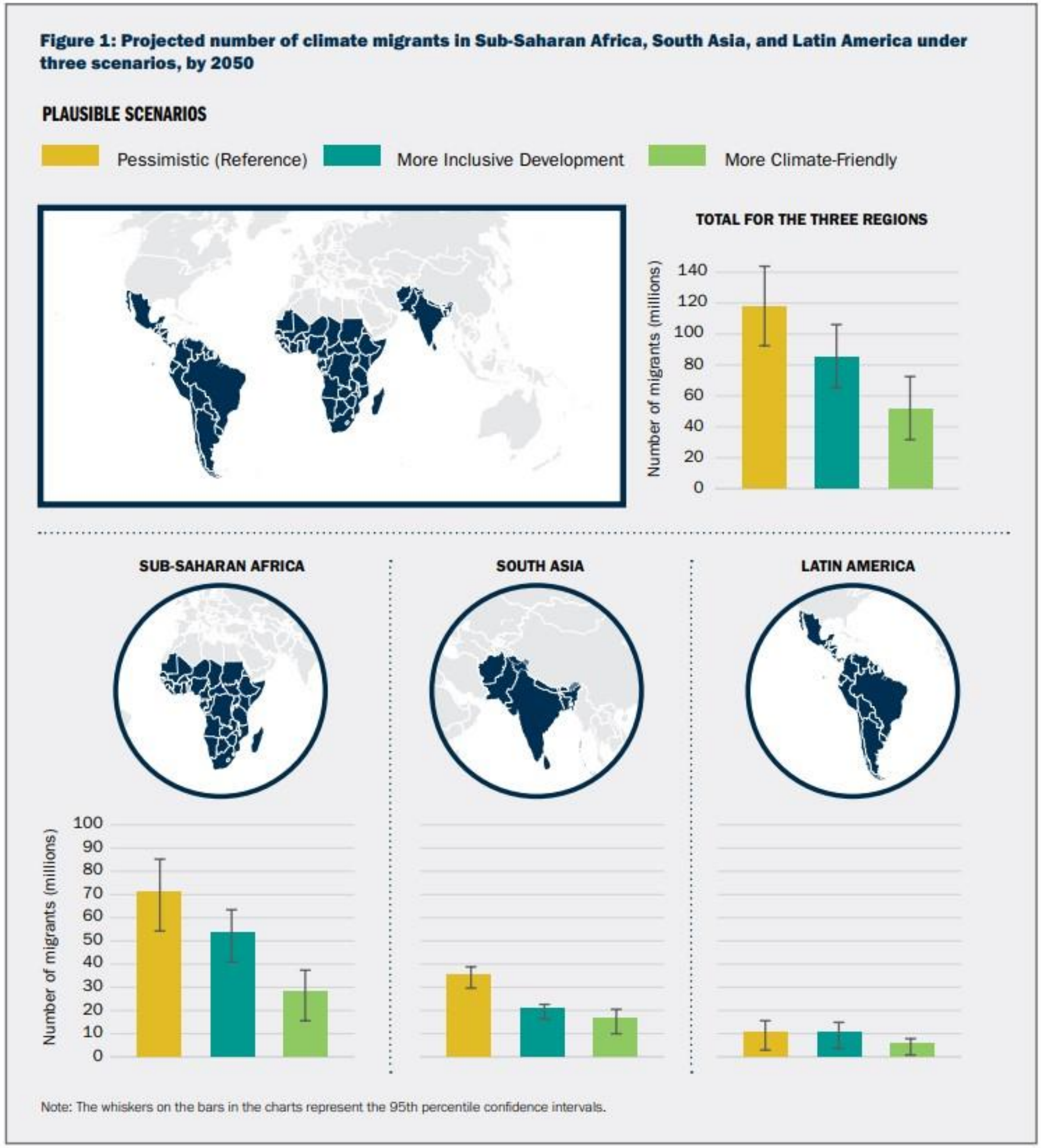


- Climate change is driving global environmental change and changes in geographic distribution of animal species
- Over 10,000 virus species potentially infective to humans are circulating silently in wild mammals
- 4,000 new cross-species transmission events are predicted to occur in wildlife due to changes in climate and land use in heavily populated regions of Asia and Africa

Source: Carlson, C.J., Albery, G.F., Merow, C. et al. Climate change increases cross-species viral transmission risk. Nature 607, 555–562 (2022). https://doi.org/10.1038/s41586-022-04788-w

Climate change and migration

- Today, around 1% of the world considered barely tolerable due to heat
- By 2050, in regions of Sub-Saharan Africa, South Asia, and Latin America, climate change could result in the forced displacement of over 143 million people within their countries
- Most will likely move into urban and peri-urban areas within their countries
- Vector-borne diseases such as malaria and dengue thrive in such crowded urban and peri-urban settings



Sources: Renee Cho. Climate Migration: An impending global challenge. State of the Planet. Columbia Climate School. May 2021: https://news.climate.columbia.edu/2021/05/13/climate-migration-an-impending-global-challenge/

Rigaud, et al.,2018. Groundswell: Preparing for Internal Climate Migration. Washington, DC: The World Bank.

Climate change, urbanization, and infectious diseases

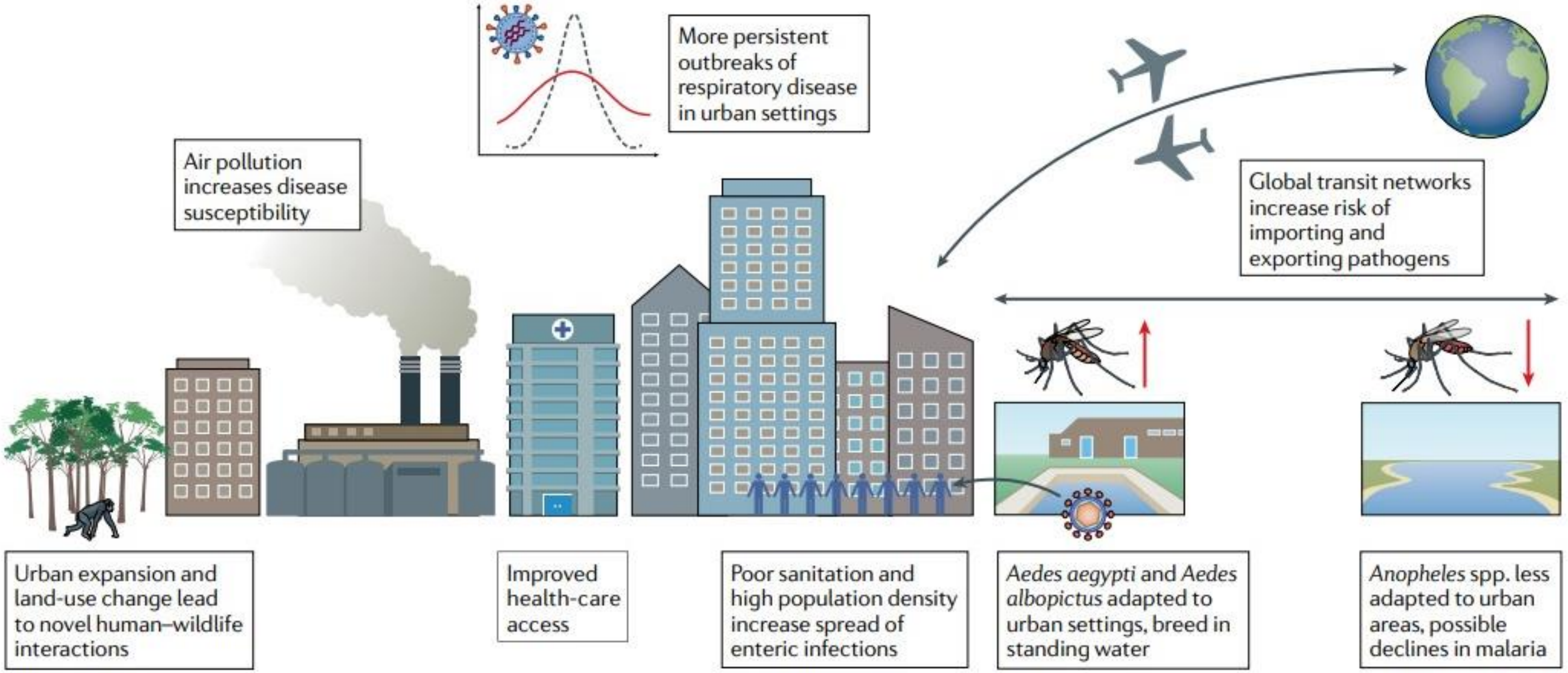
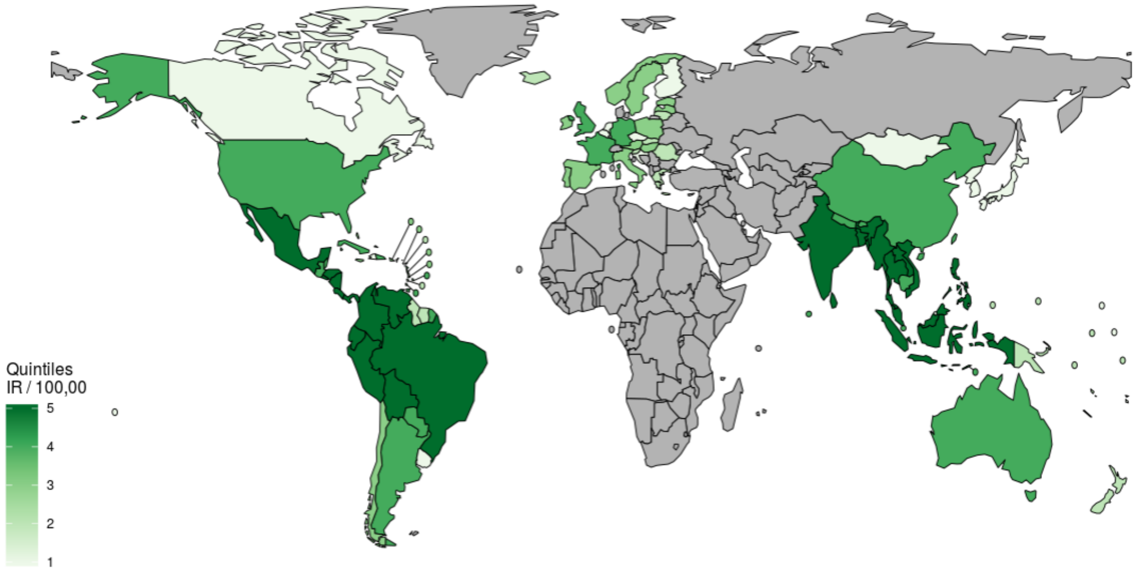


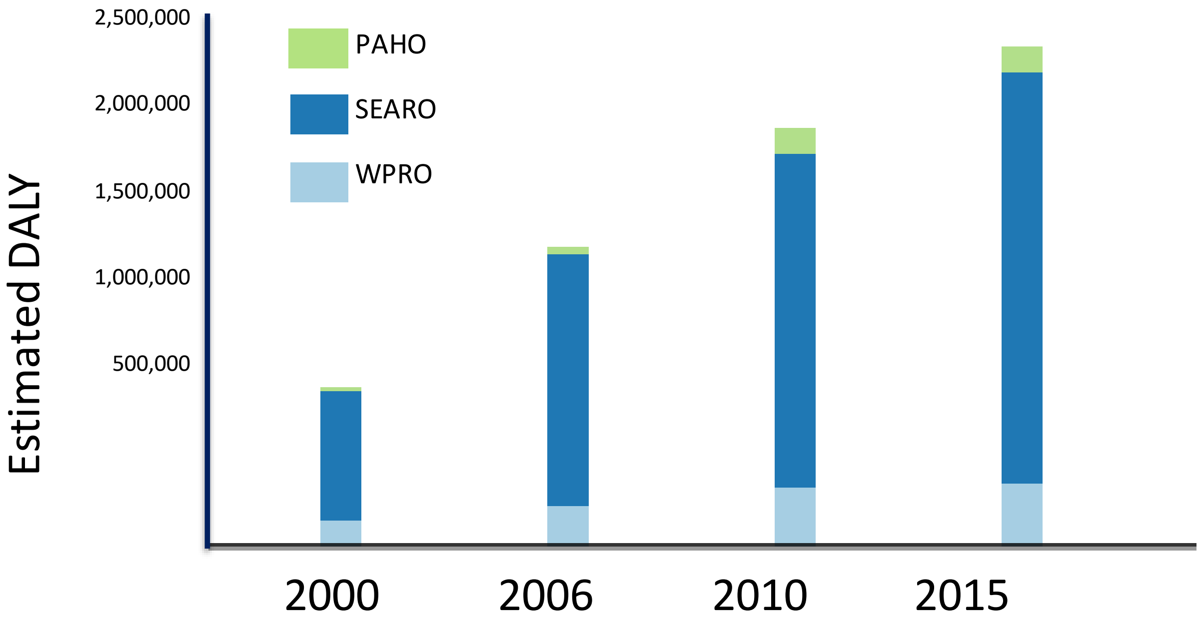
Fig. 2 | **Impacts of urbanization on infectious disease.** Interactions between urbanization and infectious disease are complex, with increased urbanization driving both positive and negative changes to global disease burden.

Source: Baker et al., Infectious disease in an era of global change. 2021. *Nature Reviews Microbiology*; https://doi.org/10.1038/s41579-021-00639-z

Global dengue trends

- Global incidence has increased significantly
- Almost half of the world's population is now at risk (100–400 million infections and 40,000 deaths)
- Risk for local transmission in the continental U.S. is influenced primarily by imported cases



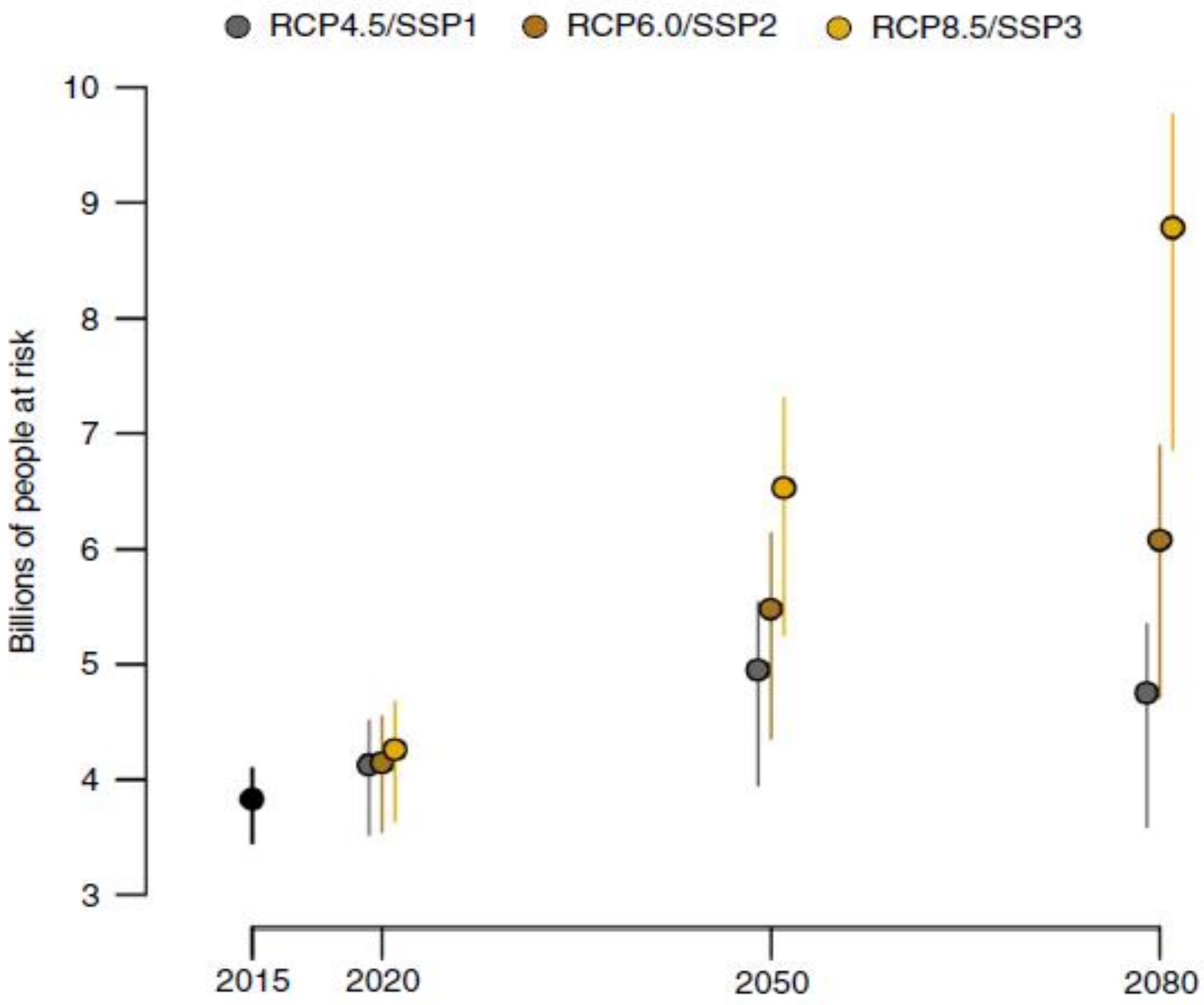


Sources: https://www.cdc.gov/dengue/about/index.html; https://www.who.int/news-room/fact-sheets/detail/dengue-and-severe-dengue

Source: https://ntdhq.shinyapps.io/dengue5/

Global dengue projections: 2020 – 2080

- Model predicts that 2.25 billion more people will be at risk of dengue in 2080 compared to 2015
- *Key drivers: urbanization, disproportionate population growth, and climate change*



Source: Messina et al., 2019. Nature Microbiology 4: 1508-15. https://doi.org/10.1038/s41564-019-0476-8

Climate change, urbanization, and infectious diseases

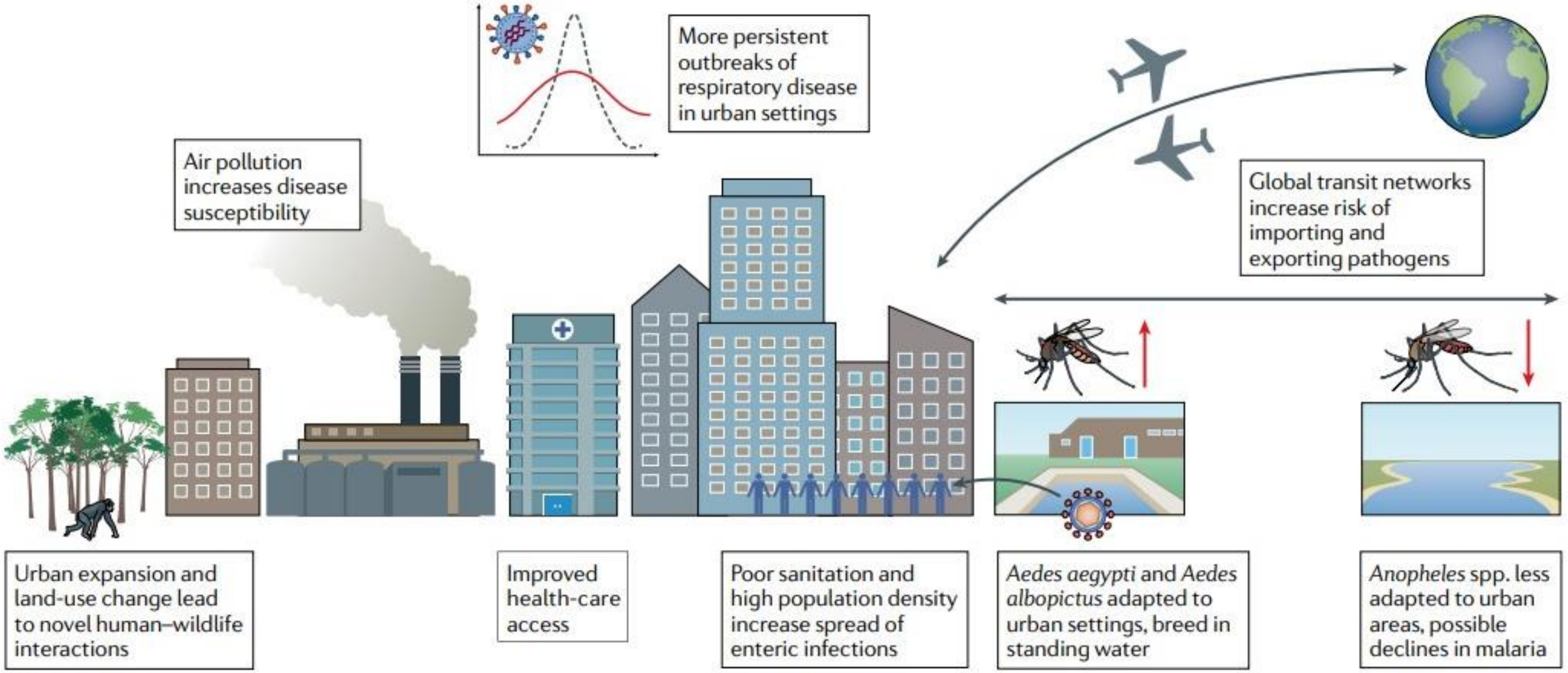


Fig. 2 | **Impacts of urbanization on infectious disease.** Interactions between urbanization and infectious disease are complex, with increased urbanization driving both positive and negative changes to global disease burden.

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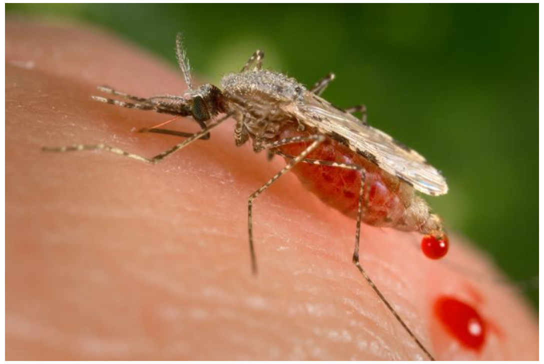
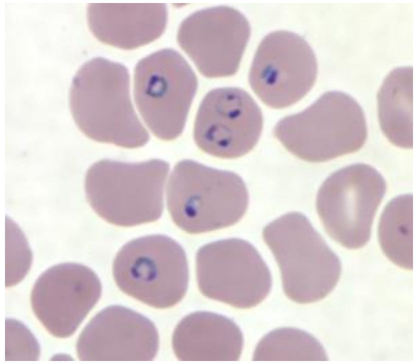
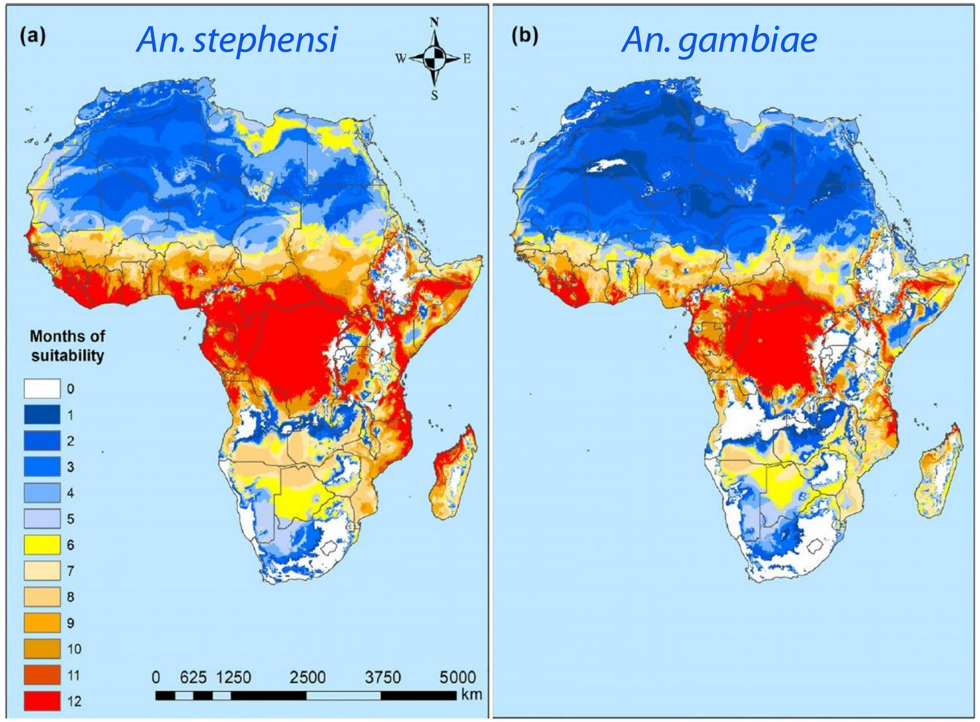
Source: Baker et al., Infectious disease in an era of global change. 2021. *Nature Reviews Microbiology*; https://doi.org/10.1038/s41579-021-00639-z

Emerging urban mosquito vector: *Anopheles stephensi*

- Efficient vector of both *P. falciparum* and *P. vivax*
- Breeds in containers and cisterns, highly adapted to urban environments, survives extremely high temperatures
- Previously confined to parts of South Asia and the Arabian Peninsula but recently collected in seven African countries
- Resistant to multiple insecticides and considered by WHO a major potential threat to malaria control and elimination in Africa and southern Asia



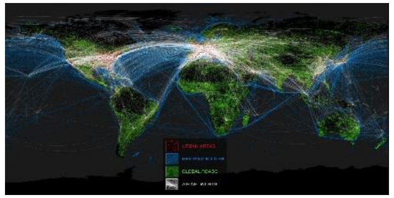


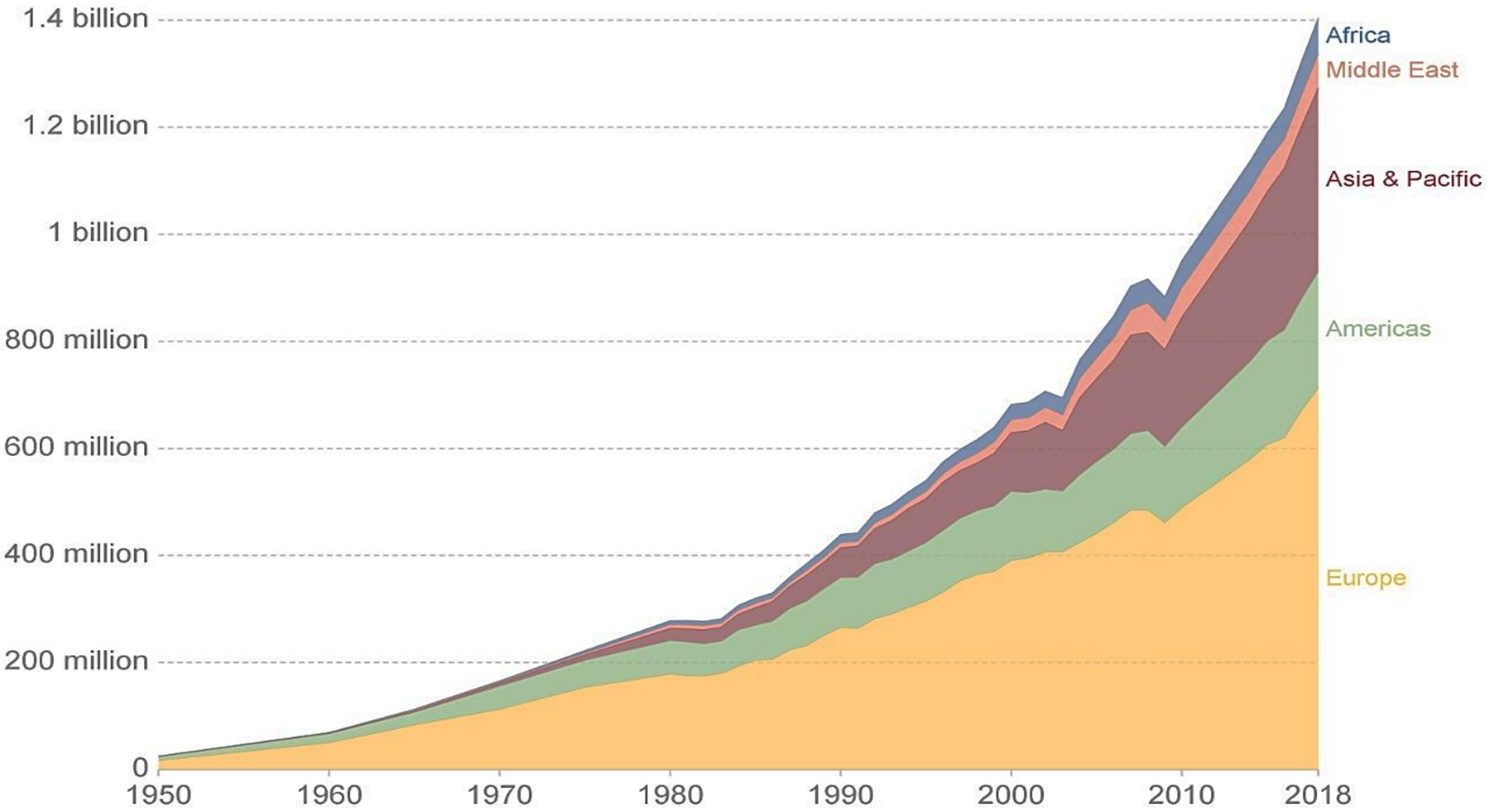


Source: Villena, Oswaldo C., Sadie J. Ryan, Courtney C. Murdock, and Leah R. Johnson. 2022. "Temperature Impacts the Environmental Suitability for Malaria Transmission by Anopheles Gambiae and Anopheles Stephensi." Ecology 103(8): e3685. https://doi.org/10.1002/ecy.3685

Sources: WHO 2019. https://iris.who.int/handle/10665/326595; and
WHO, 2023. Malaria. https://www.who.int/news-room/fact-sheets/detail/malaria

International tourist arrivals by world region

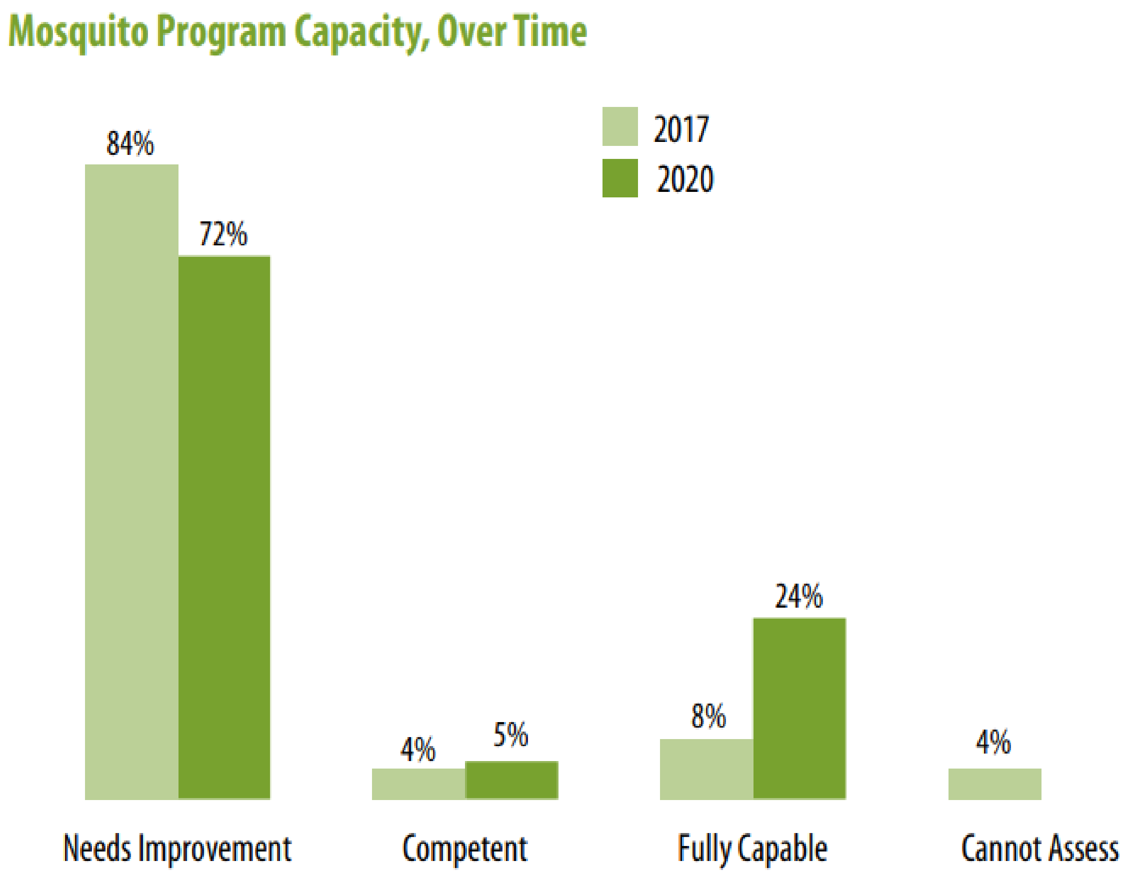


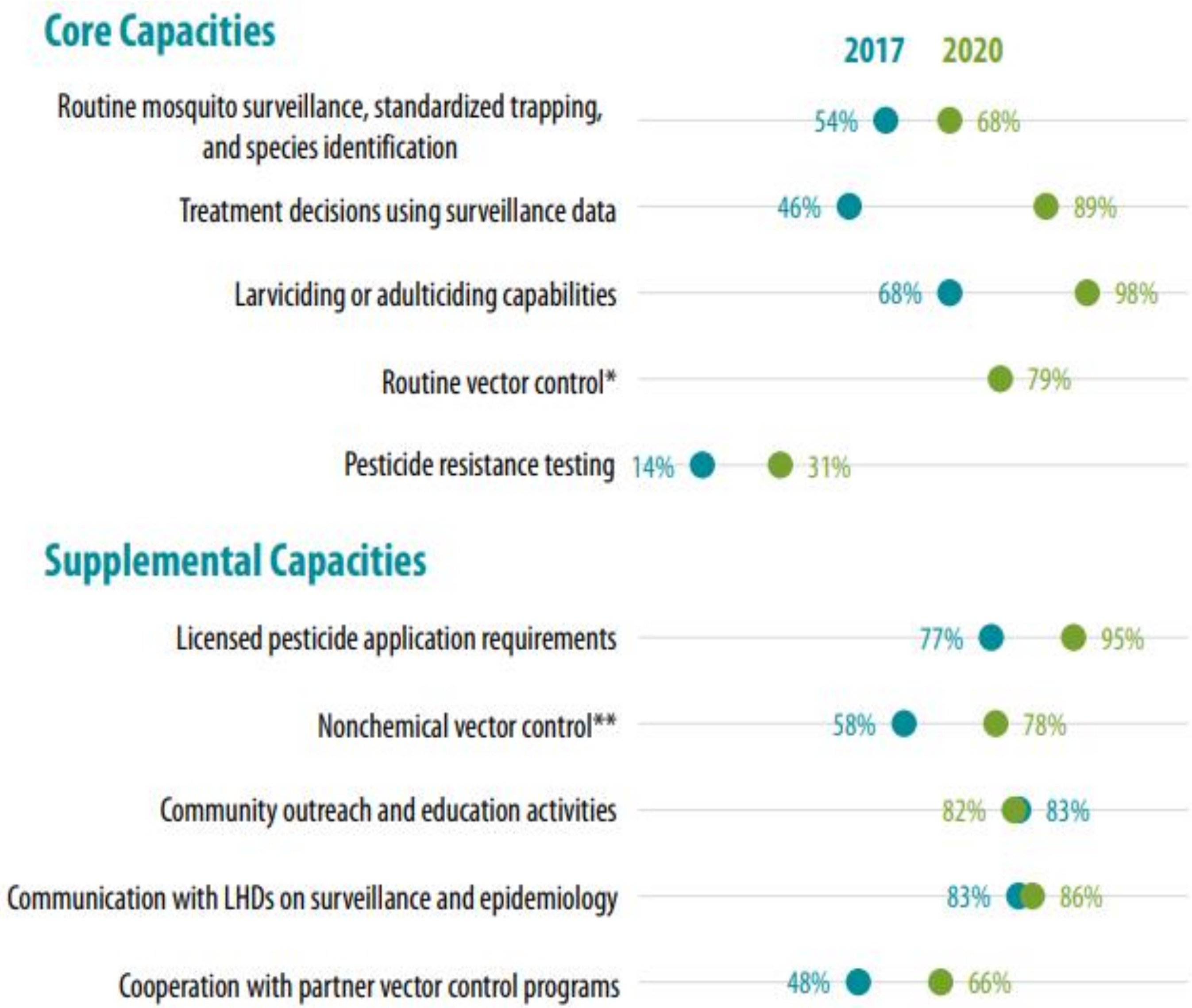


Source: United Nations World Tourism Organization – World Tourism Barometer (2019)

Promising developments

Mosquito surveillance and control capacity



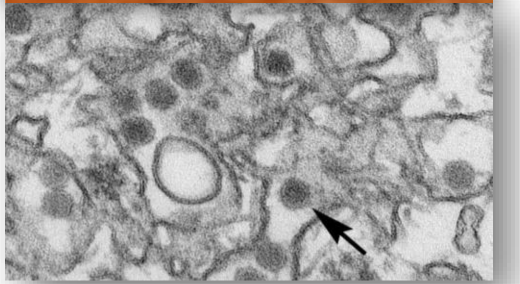


Source: Roy H, Gridley-Smith C, Chatelain D, McCall TC, Brees K, Hall K, Anupama V. 2022. Vector Surveillance and Control at the Local Level. National Association of County and City Health Officials (NACCHO). https://www.naccho.org/uploads/downloadable-resources/Vector-control_2020-assessment-report_Final.pdf

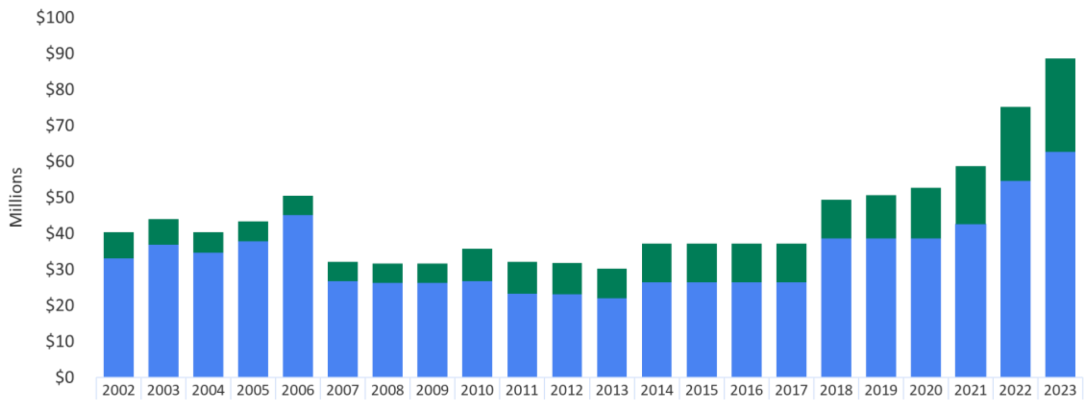
Select novel technologies being developed and evaluated

Technology
Wolbachia population suppression and replacement
Gene-edited mosquitoes (SIT, Self-limiting genes, CRISPR/Cas-9, etc.)
Irradiation
Lethal traps
Spatial repellants/insecticide vapor emanators
New active ingredients



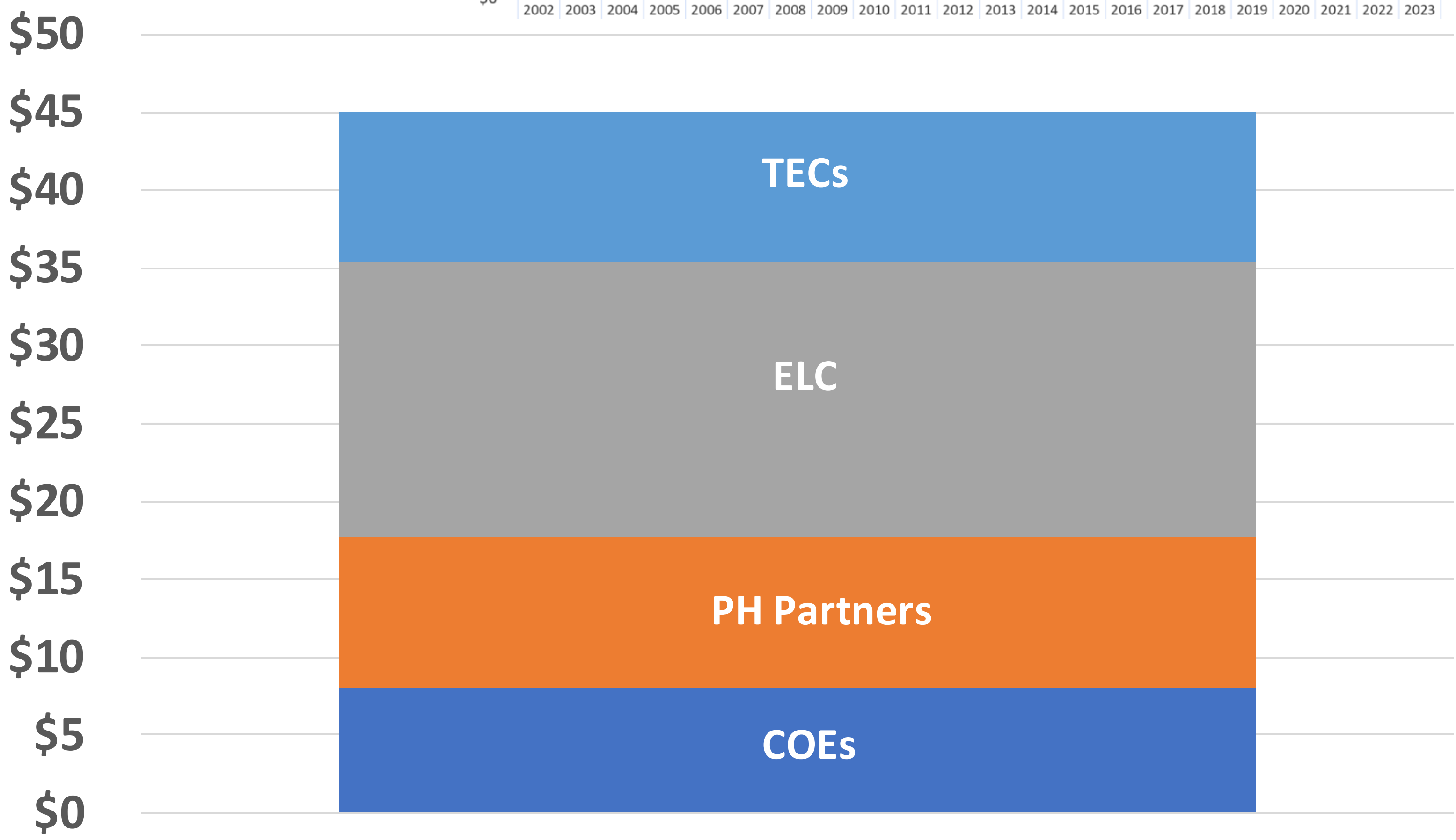
FY2023 domestic cooperative agreement funding, in millions



$45,041,346 Total

- Training and Evaluation Centers[1]
- Regional COEs[2]
- ELC Cooperative Agreement[3]
- Domestic partners

[1] Five Centers and two special projects
[2] Four Centers
[3] 64 recipients, mostly state and territorial health departments. Does not including ~$20M one time hurricane funding (FY23/24)
[4] 17 partners both in CONUS and in US territories



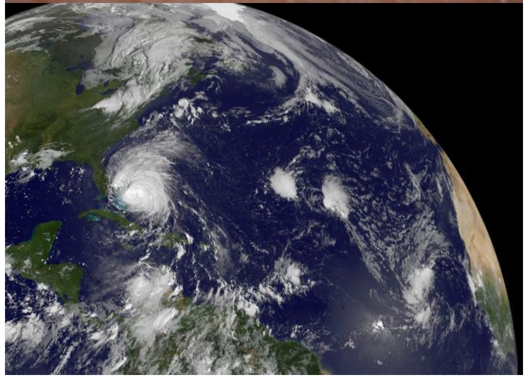
Future challenges and opportunities

- Longer transmission seasons*
- Expanding geographic distributions*
- Increasing risk of exotic introductions and subsequent transmission due to increasing global incidence, travel and trade, and changing habitat suitability
- Likelihood of more frequent extreme weather events
- Vector management challenges and improvements
- Novel and promising technologies
- Strong support and collaboration

*More relevant to temperate regions

Conclusions

- Factors driving VBD emergence are complex and include multiple factors
- Climate change will likely enhance other drivers including broader environmental change, population migration, and urbanization, which will likely have a greater impact than the direct effects on vector populations
- Larger numbers of people in concentrated areas are likely to be exposed to emerging vector-borne diseases
- The burden of health impacts will be most significant in the Global South
- Vector control activities are likely to be complicated by the effects of climate change population movements, political instability, and insecticide resistance
- A coordinated, multifaceted global response will be required to address these concerns



Chat GPT’s conclusion on the topic…

In a world with a warming embrace,
Vector pests find a flourishing space.
With climates askew,
They multiply, it's true,
Spreading diseases, we all must face.

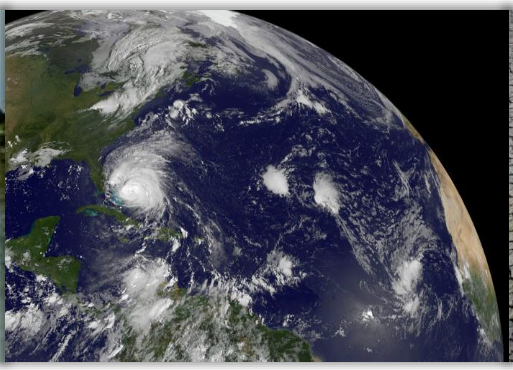
Acknowledgments

Many DVBD staff, but special thanks to…

- Lyle Petersen
- Sue Visser
- Ann Powers
- Jeff Borchert
- Jessica Sweeney
- Lacey Avery

Thank you and questions



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