# *The Impact of Climate and Environmental Changes on Infectious Diseases*

**David N. Fisman, MD MPH FRCPC**

***Professor, Dalla Lana School of Public Health, University of Toronto***

*AMMI—Canada Annual Meeting*
*Victoria, British Columbia, April 3, 2014*

AMMI Canada
Association of Medical Microbiology and Infectious Disease Canada
l'Association pour la microbiologie médicale et l'infectiologie Canada

# Conflict of Interest Disclosure Slide

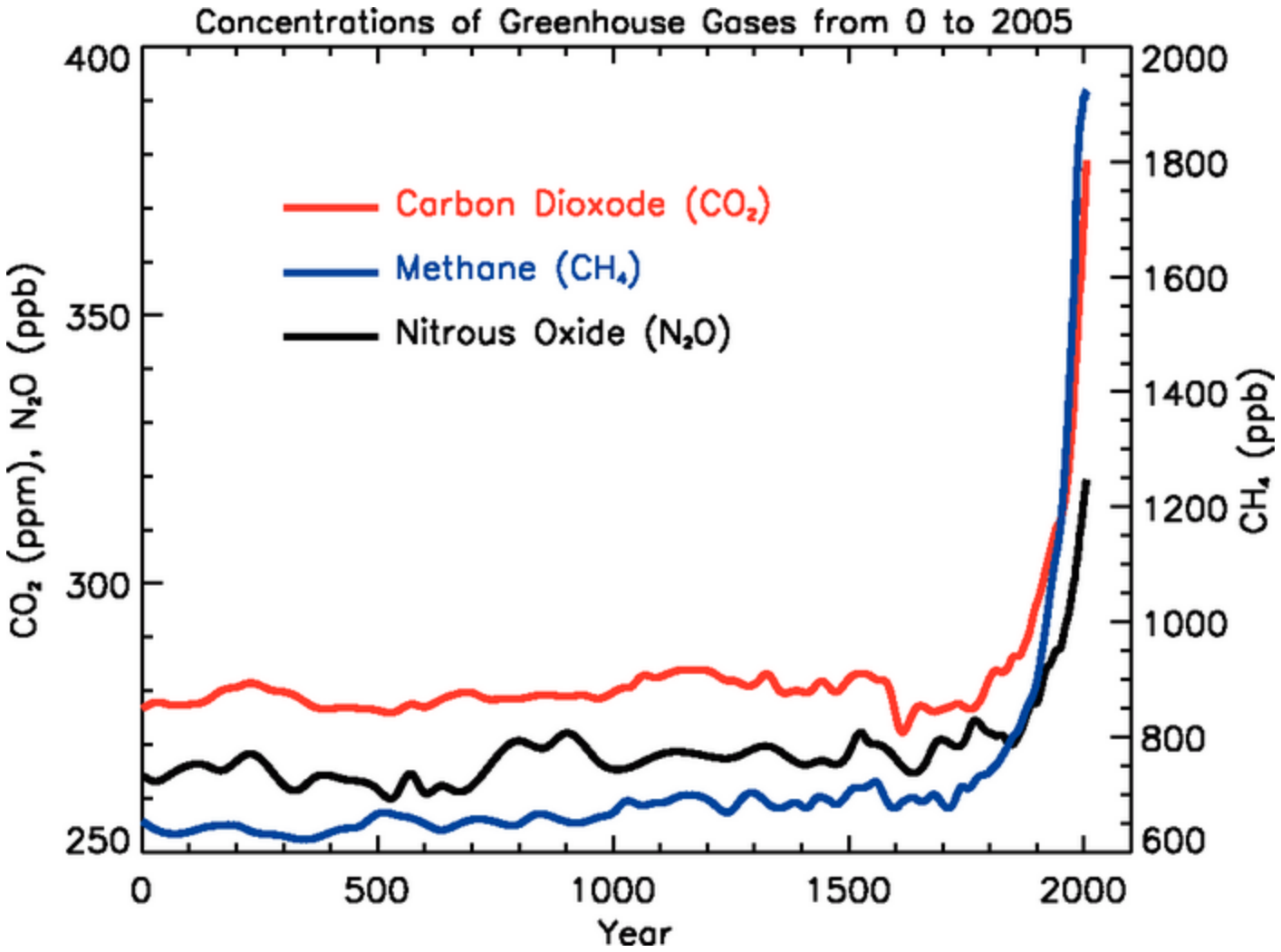
| | |
|---|---|
| In the past 2 years I have been an employee of | The University of Toronto |
| In the past 2 years I have been a consultant for | Novartis Vaccines |
| In the past 2 years I have held investments in the following pharmaceutical organizations, medical devices companies or communications firms | None ☹ |
| In the past 2 years I have been a member of the Scientific advisory board for | Nobody ☹ |
| In the past 2 years I have been a speaker for | Nobody ☹ |
| In the past 2 years I have received research support (grants) from | CIHR, US Nat'l Sci Foundation, Novartis Vaccines |
| In the past 2 years I have received honoraria from | Nobody ☹ |
| I agree to disclose approved and non-approved indications for medications in this presentation. | Yes |
| I agree to use generic names of medications in this presentation. | Yes |

**Also: I am Director of the FitzGerald Seminar Series at University of Toronto, which is generously supported by Novartis Vaccines, GSK Vaccines, and Merck Vaccines**

# *Outline*

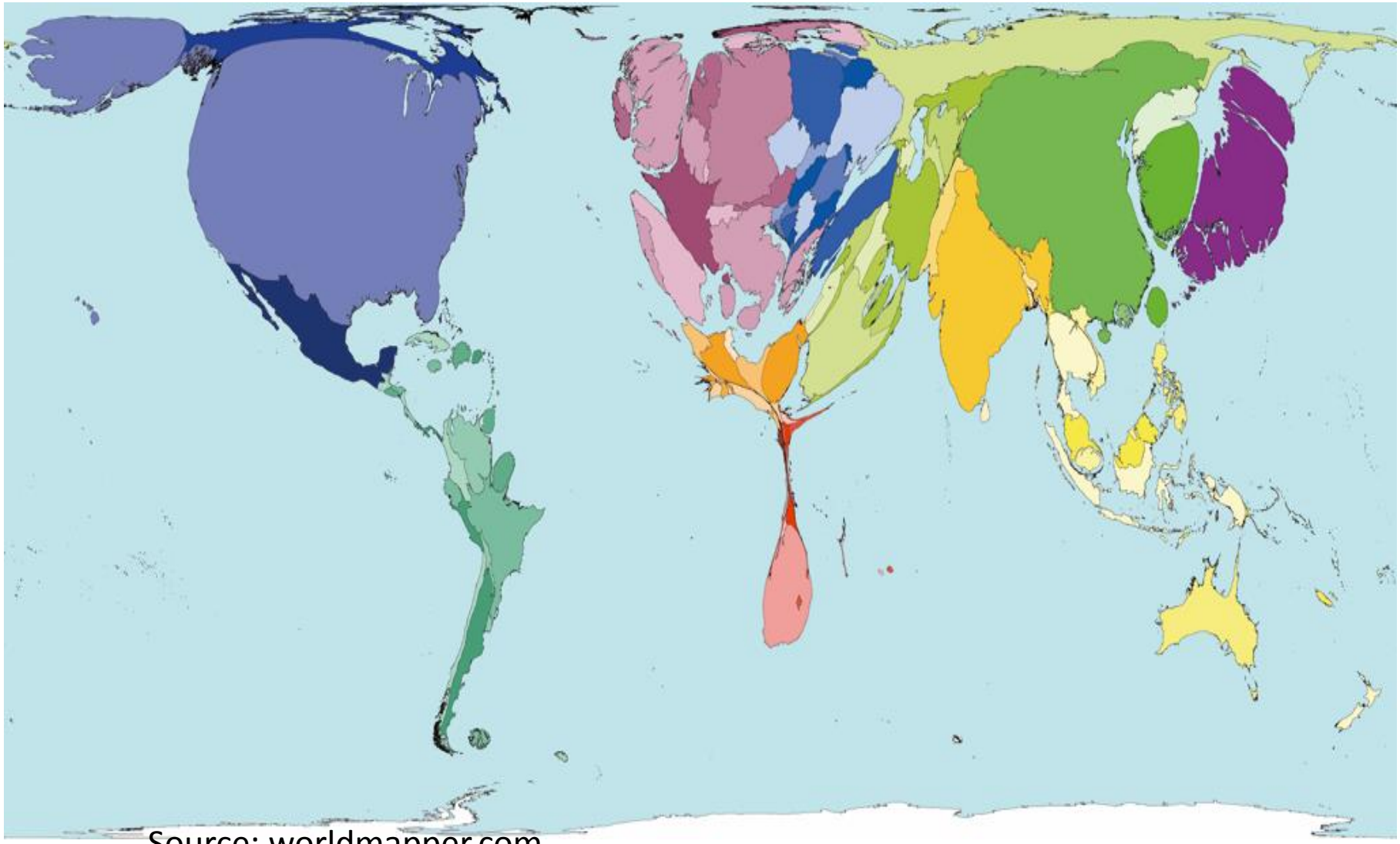
- Climate change:
  - Concepts, trends and projections.
- Ecology, climate change and infectious diseases:
  - Vectorborne diseases.
    - Lyme.
    - West Nile.
  - Water- and foodborne pathogens.
  - [Not covered: influenza, nosocomial pathogens, endemic mycoses]
- Mitigation and vulnerability.

# Greenhouse Gases ($CO_2$ and $CH_4$)



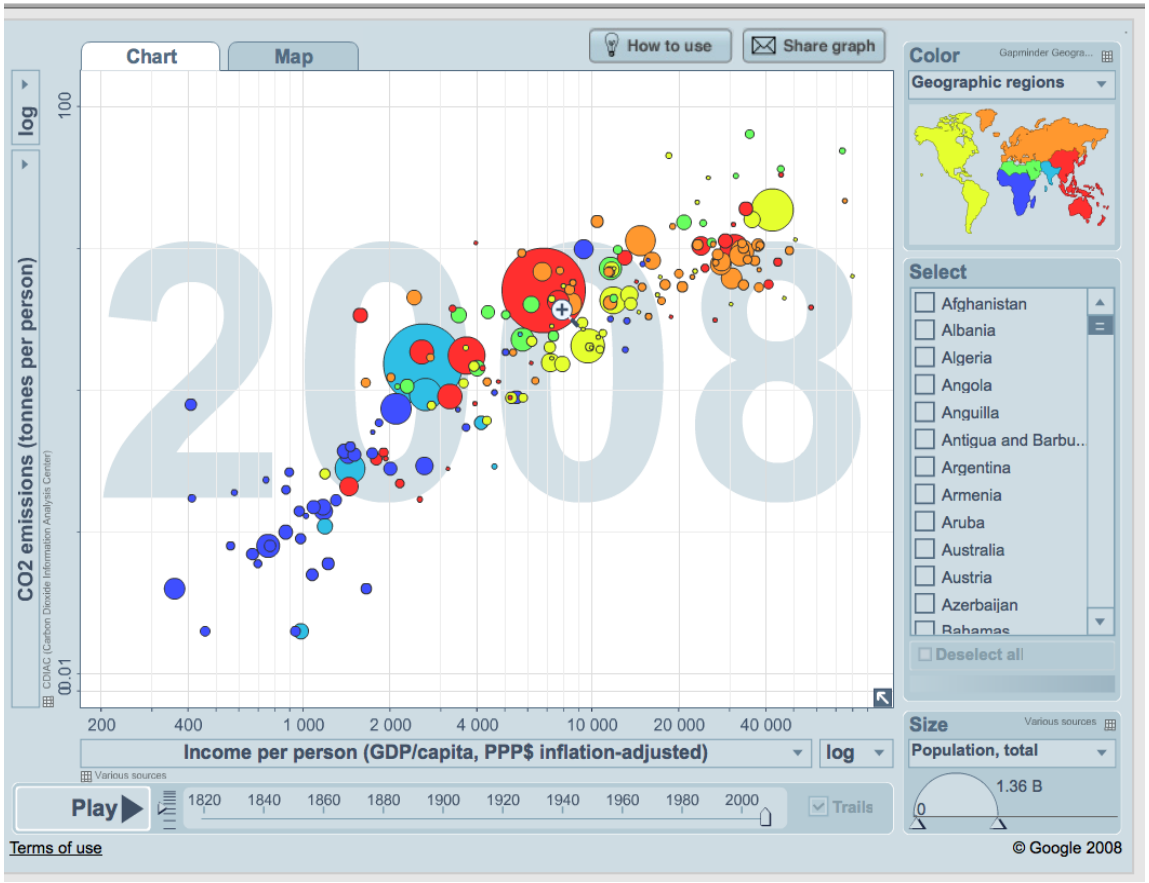

- (IPCC, 4th Assessment Report, 2007)

# *Relative Carbon Emissions*



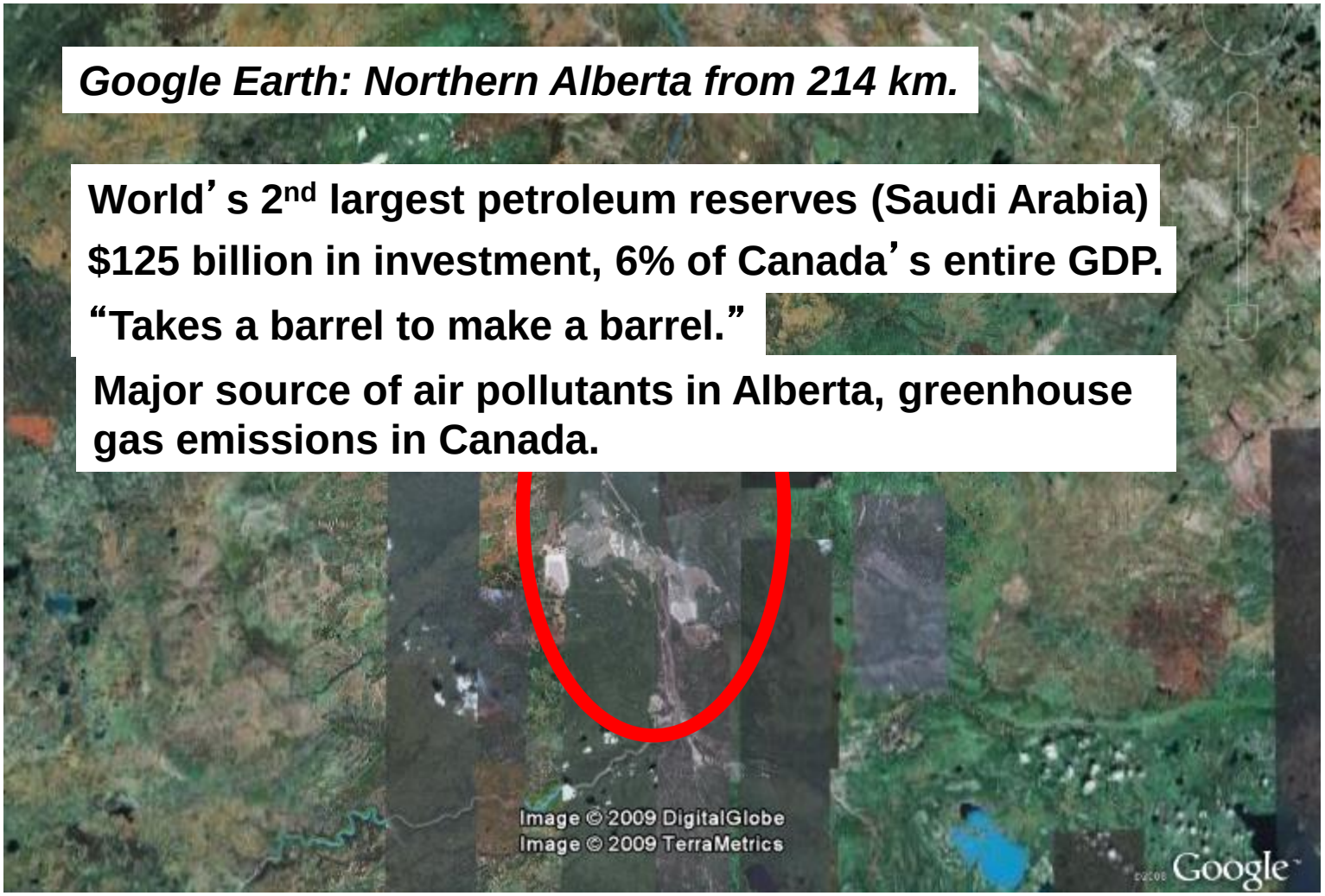
Source: worldmapper.com

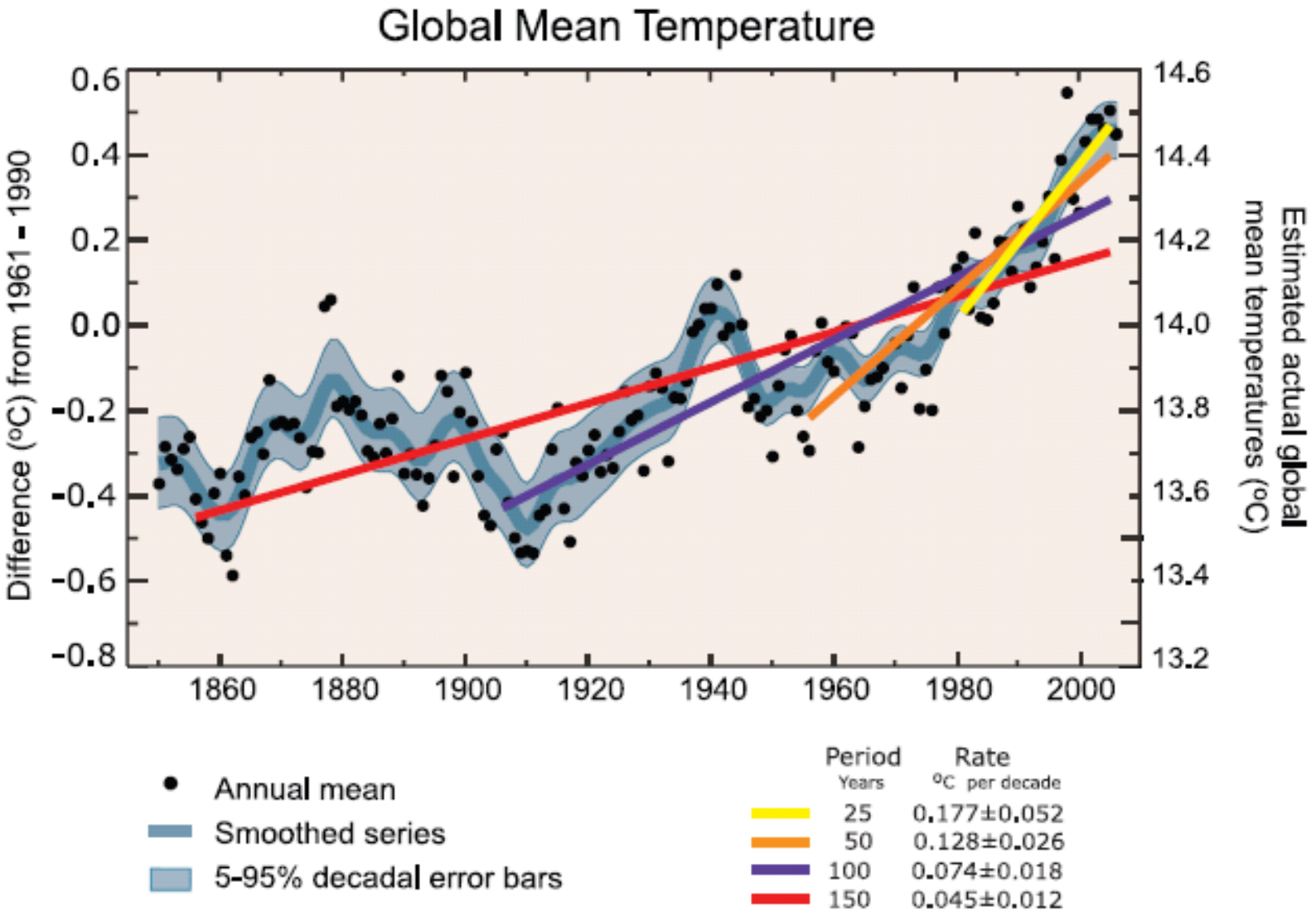
# Carbon Emissions per Capita vs. Per Capita GDP (2008)




Source: gapminder.com

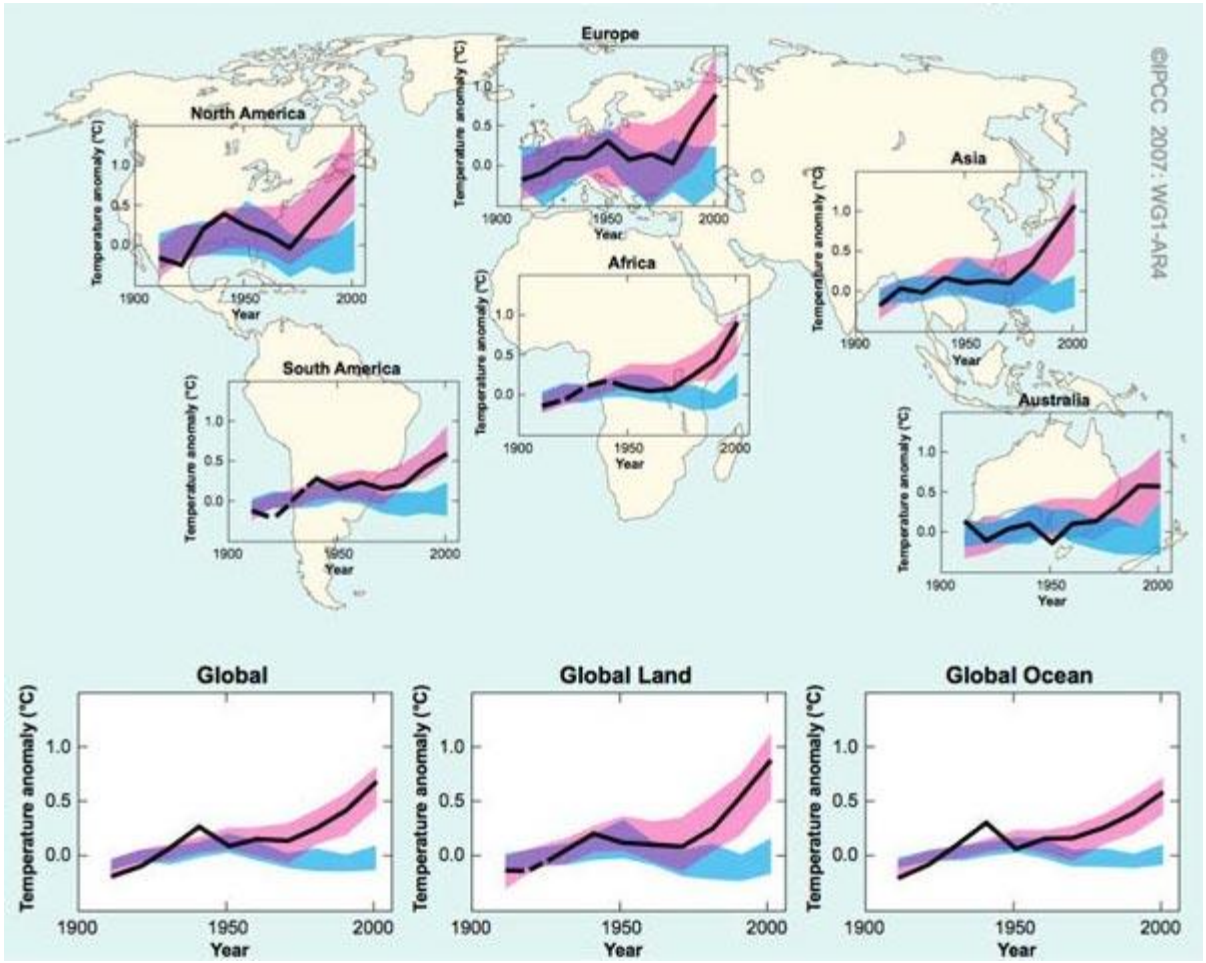
# Canada's Carbon Footprint





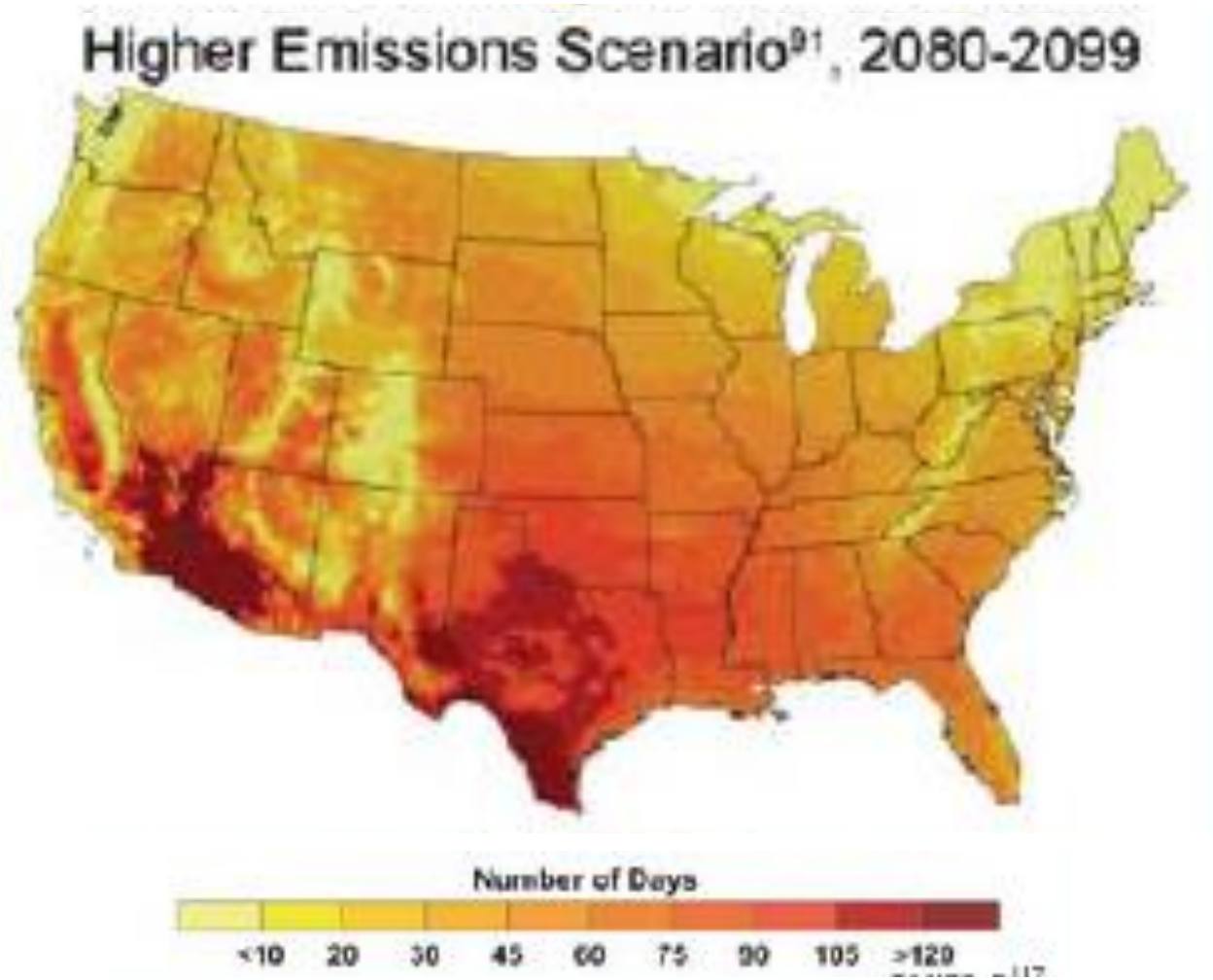

- Accelerating pace of global warming (IPCC, 4th Assessment Report, 2007)

# *Anthropogenic Greenhouse Gases*




- (IPCC, 4th Assessment Report, 2007)

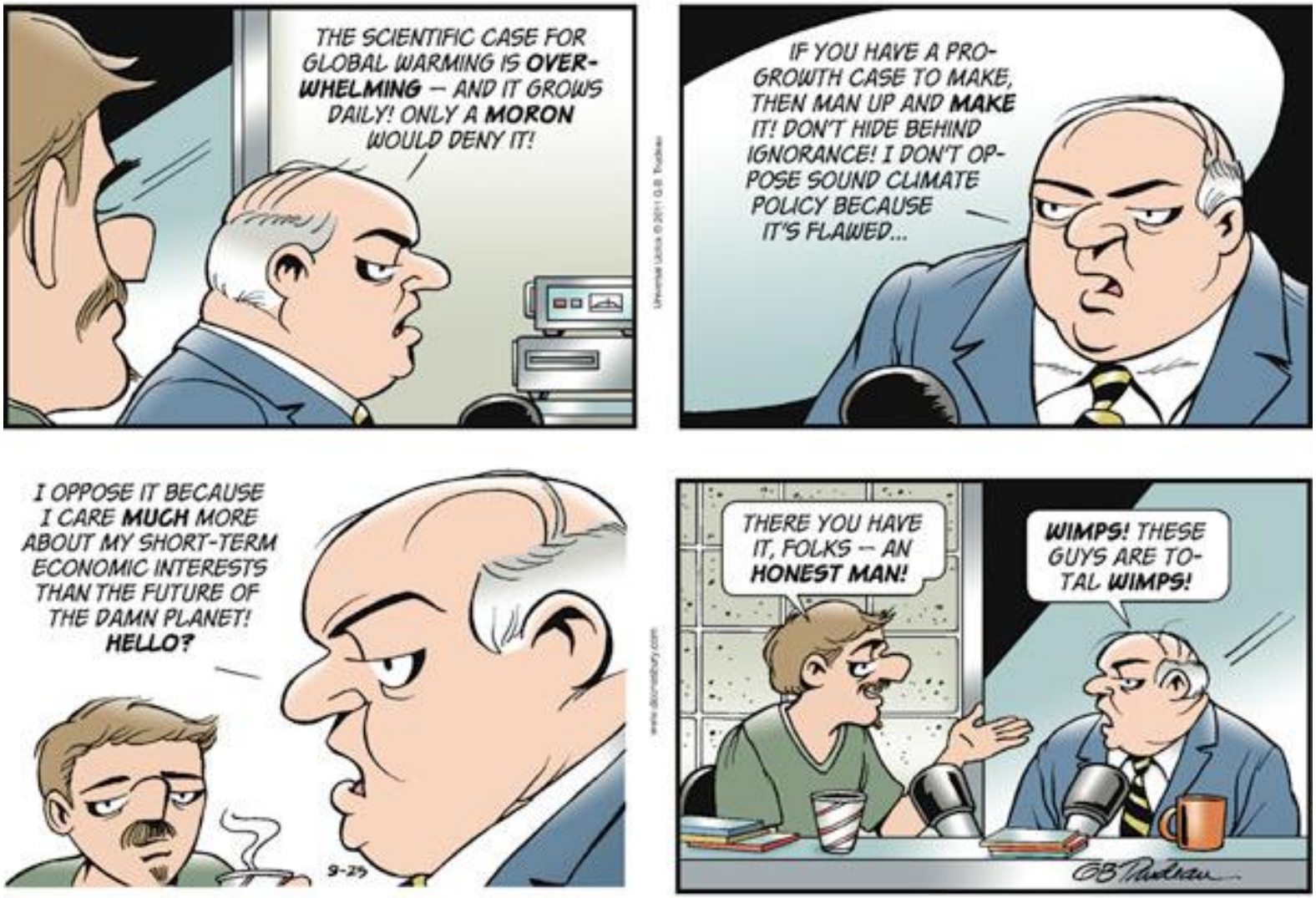
# NOAA Report (June 12, 2009)



# *Already a Reality*

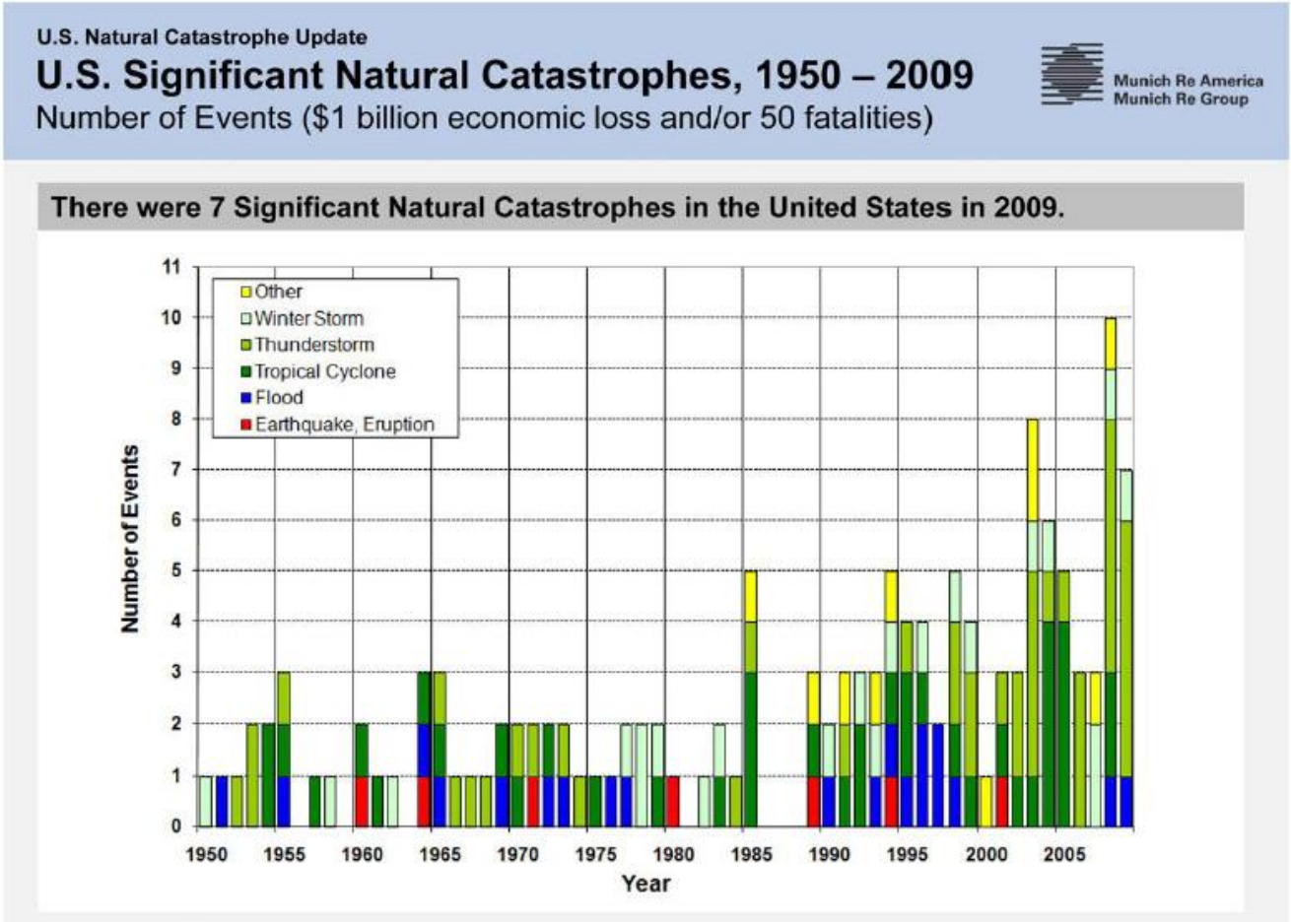

[Source: Lukaj Bogotaj, IPCC Pre-Meeting, Warsaw, October 2, 2010]

# Hard Choices




http://www.doonesbury.com/strip

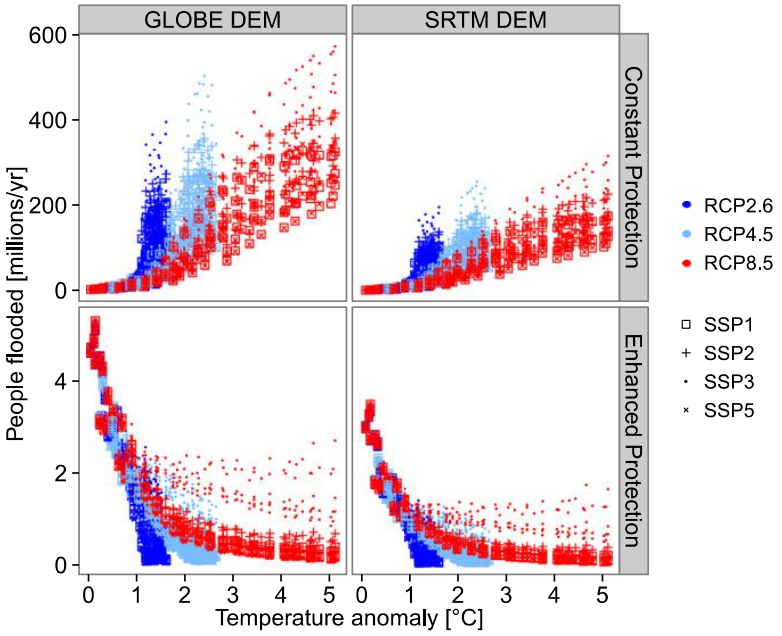
# *Disaster Frequency and Climate Change*



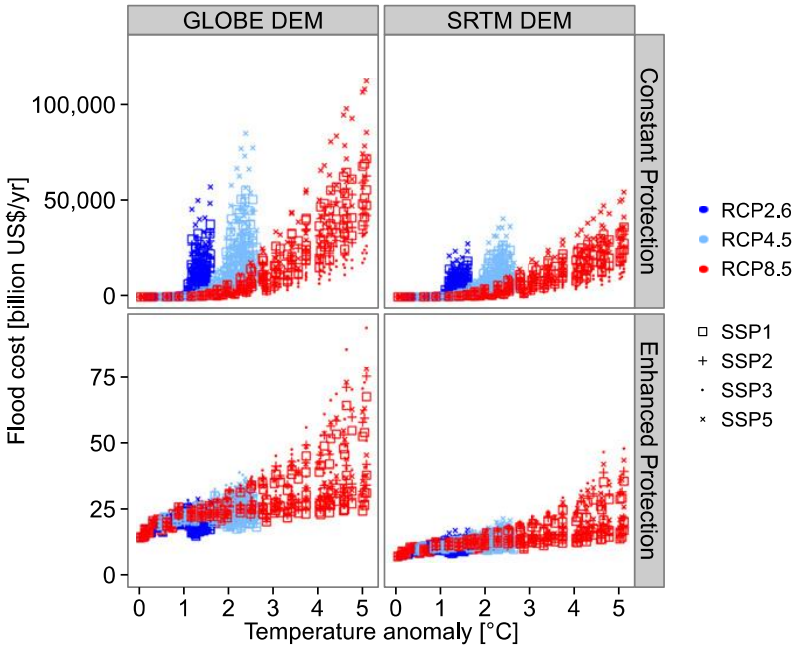

Source: Frank Nutter, Institute of Medicine panel on IEQ and Climate Change, June 7, 2010

# Infrastructure Costs: Sea Level Rise

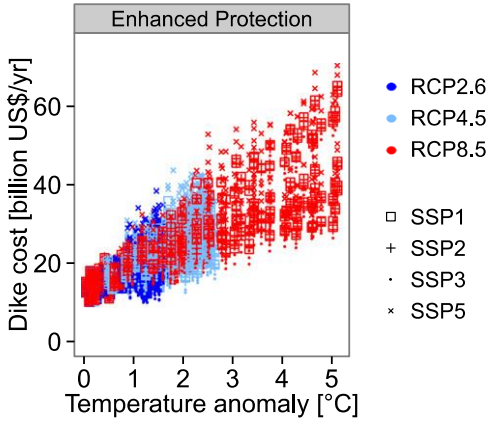
## POPULATION AT RISK




## COST




## ANNUAL INVESTMENT REQUIRED




Source:
Hinckel J et al.,
Proc Natl Acad
Sci USA 2014

# Infrastructure Costs

**"Our infrastructure is basically built from a historical perspective, looking at the last hundred years and the extremes we've seen, and building those extremes into the design. Well, from a climate change perspective, that's the equivalent of driving down the road by looking in your rear-view mirror."**

-Jason Thistlethwaite, University of Waterloo Climate Adaptation Project (http://adaptnowcanada.ca/), quoted in MacLean's Magazine, March 2012 (http://www.macleans.ca/society/the-winter-that-ruined-everything/)

# Projections on Climate Change in North America

- Intergovernmental Panel on Climate Change (IPCC) 4th Assessment, 2007
  - Increased temperatures
  - Increased rainfall
  - Increased drought & wildfire
  - Increased frequency of “extreme” weather events

# Impact on Ecosystems

- **Ecosystem:** complex biological systems with living and non-living components.
- **Physical impact on ecosystems:** changing temperatures, water availability, ocean pH (via $CO_2$) and frequency of extreme events (fires, floods, extreme rainfall) stresses living components of environment.

# *Health Effects of Climate Change*

- ***Direct consequences***
  - Heat-related mortality.
  - Injuries (e.g., due to hurricanes, tornadoes and fires).
  - Displacement of populations (coastal flooding, desertification).
- ***Indirect consequences***
  - Changes in the incidence and distribution of infectious diseases.
  - More complex causal pathways: enhanced infectious disease transmission due to displacement of populations.

# *Potential Impacts on Infectious Disease*

- **Vector-borne disease:** changing ecosystems, ranges of amplifying hosts and insect vectors.
- **Diseases with environmental reservoirs:** Effects on food, water sources; “innoculation” via extreme weather events (e.g., melioidosis).
- **Communicable diseases (esp. respiratory pathogens):** perturbations of seasonal patterns of transmission (environmental change); mass movement and crowding of populations via social disruption.

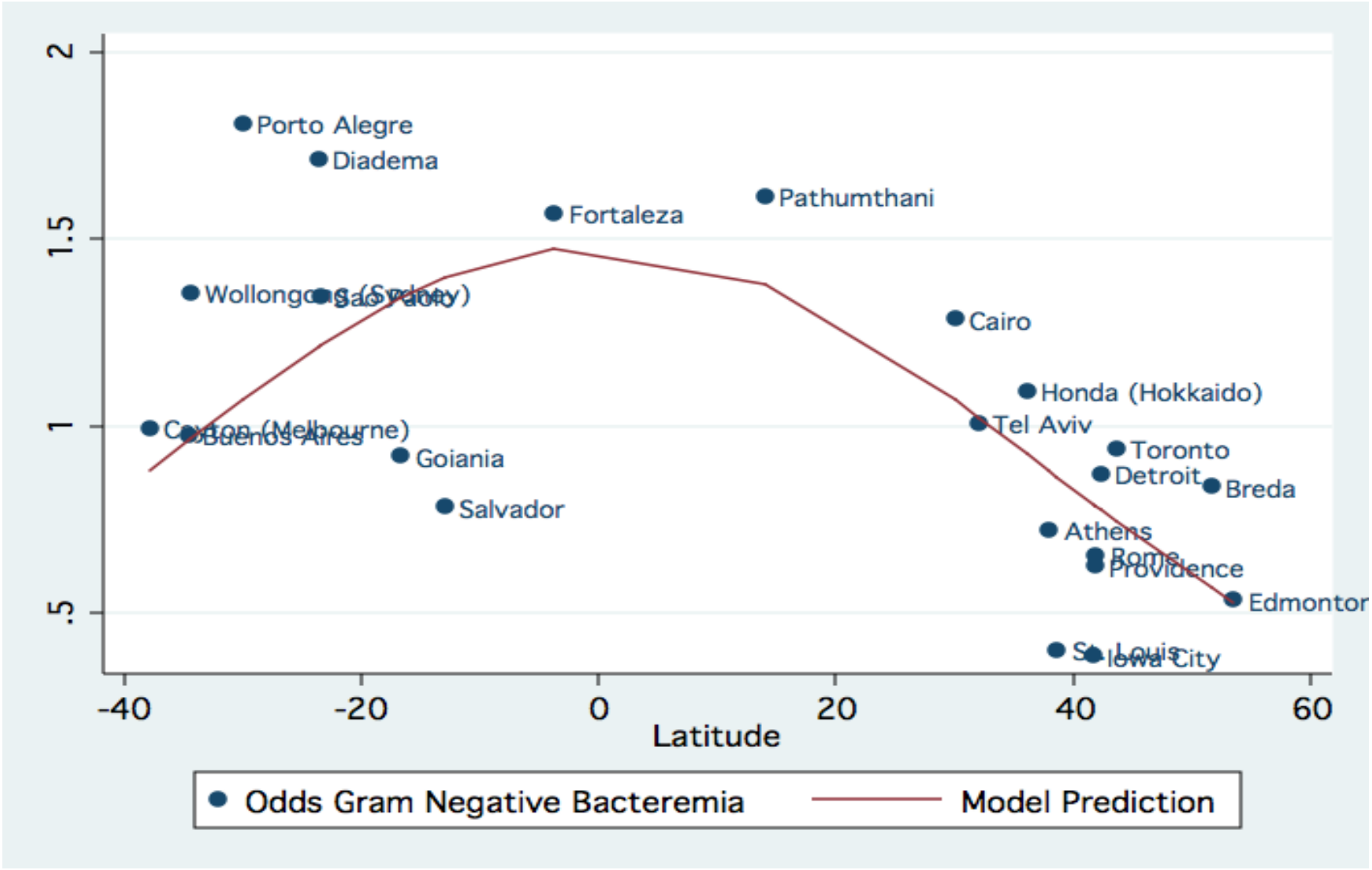
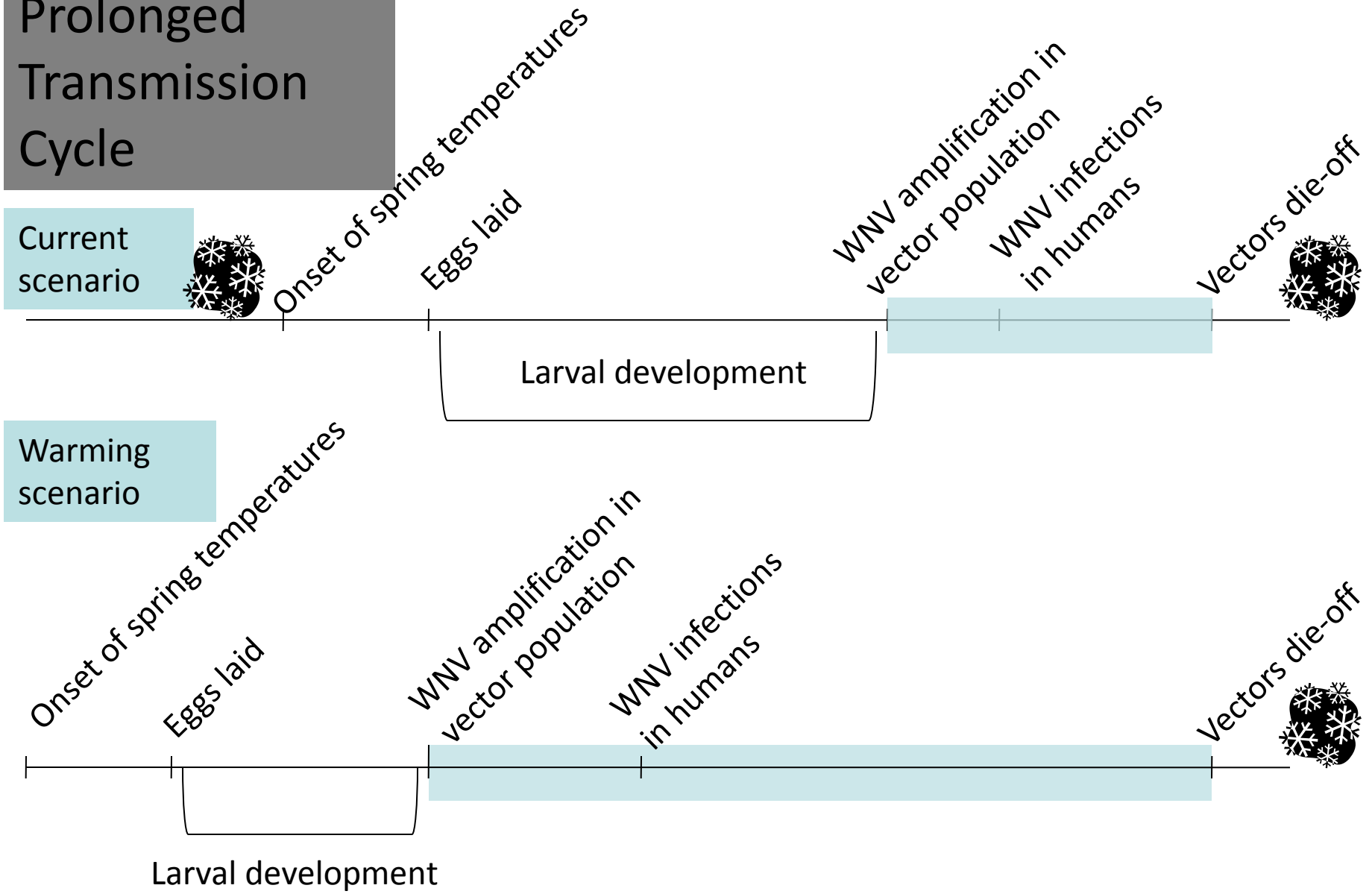



**Figure 1:** The quadratic relationship between latitude and odds of Gram-negative bacteremia in hospitalized patients with bacteremia in 22 cities (P = 0.002). These data are consistent with prior reports of elevated risk of Gram-negative bacteremia with warmer temperatures, and have important implications for climate change.

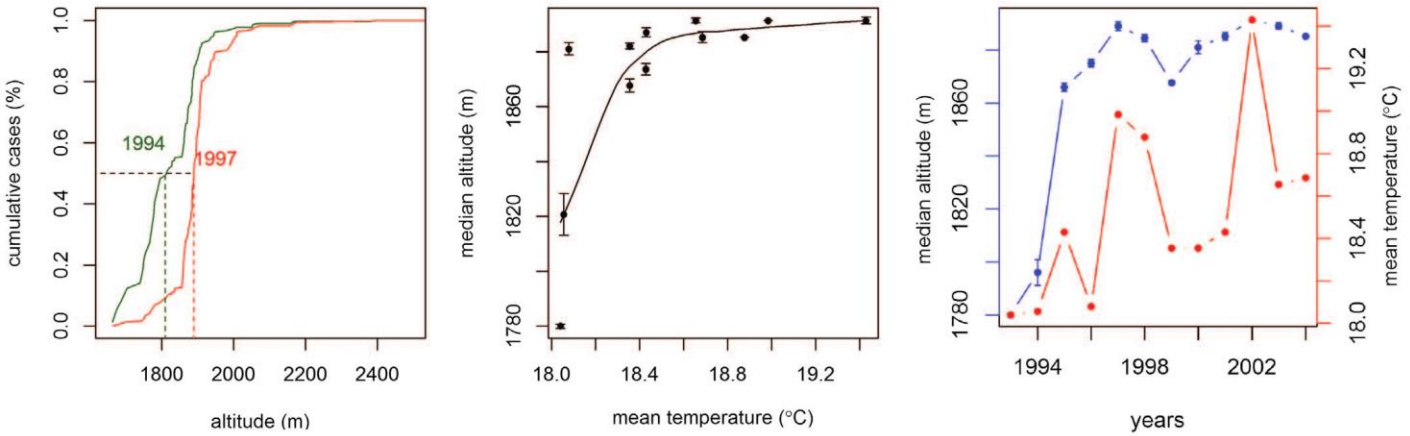
# *Vector-borne Disease*

# Prolonged Transmission Cycle

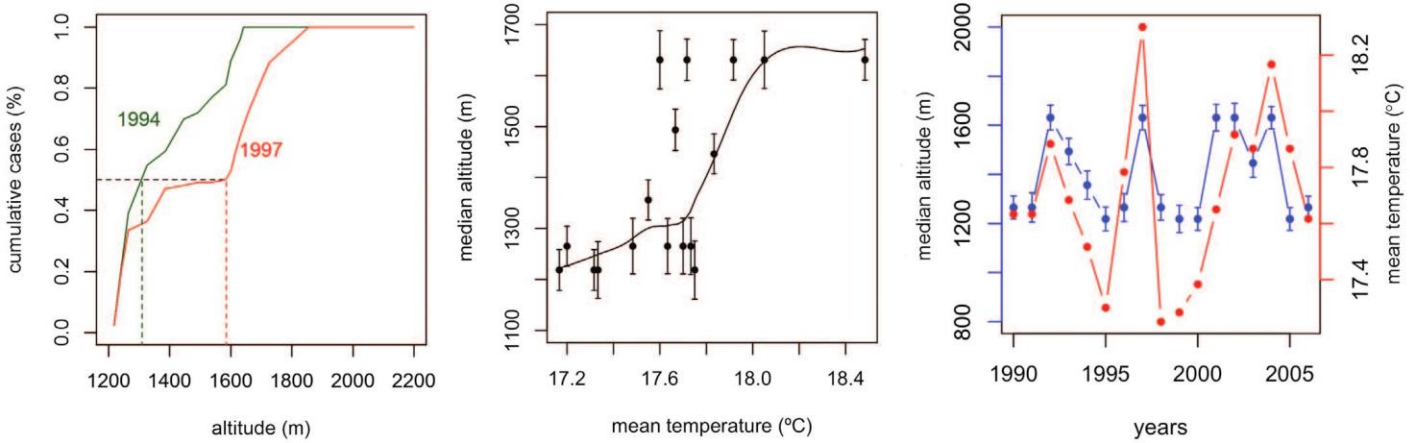


# Malaria and Altitude

Ethiopia

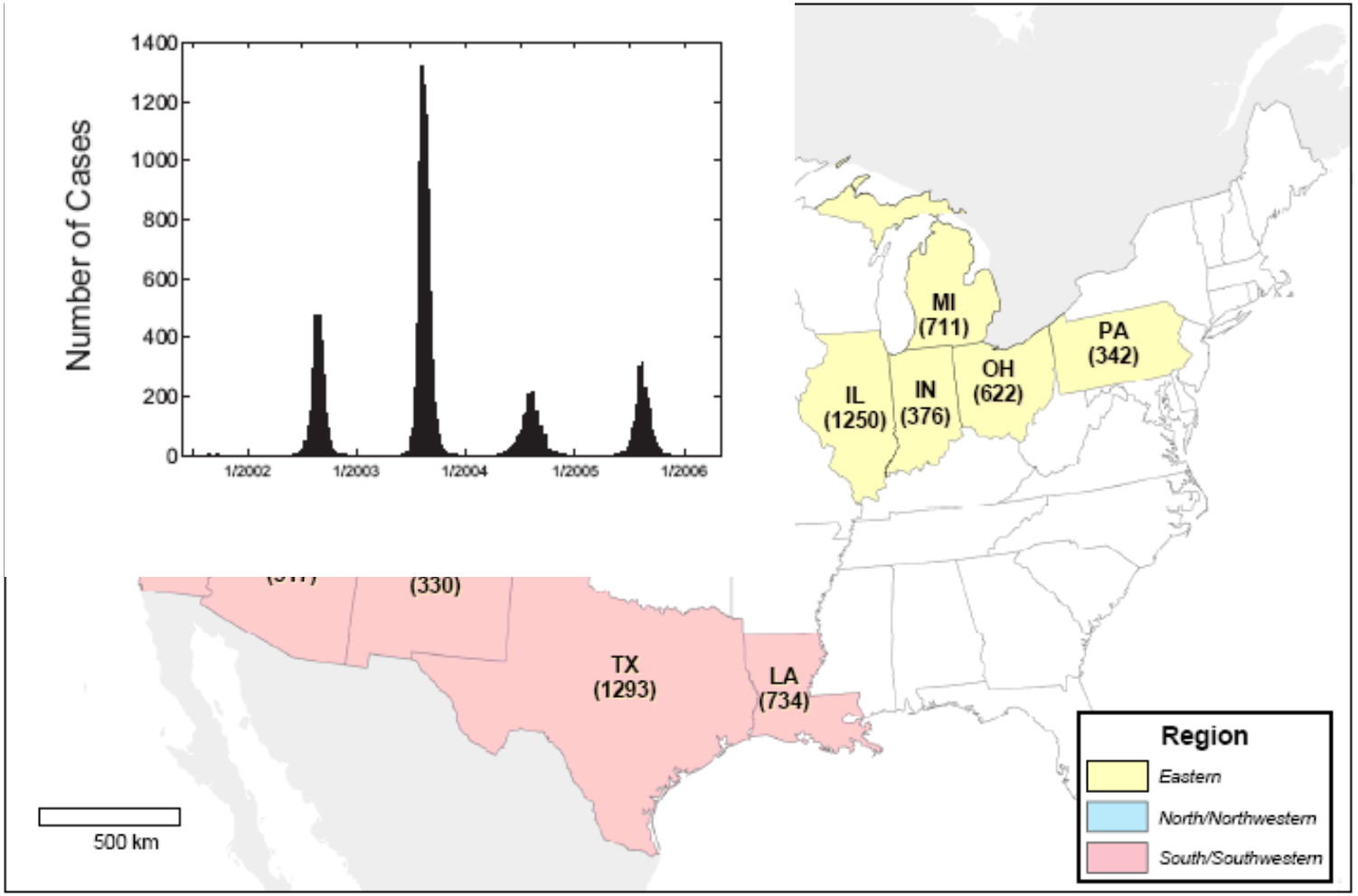



Colombia

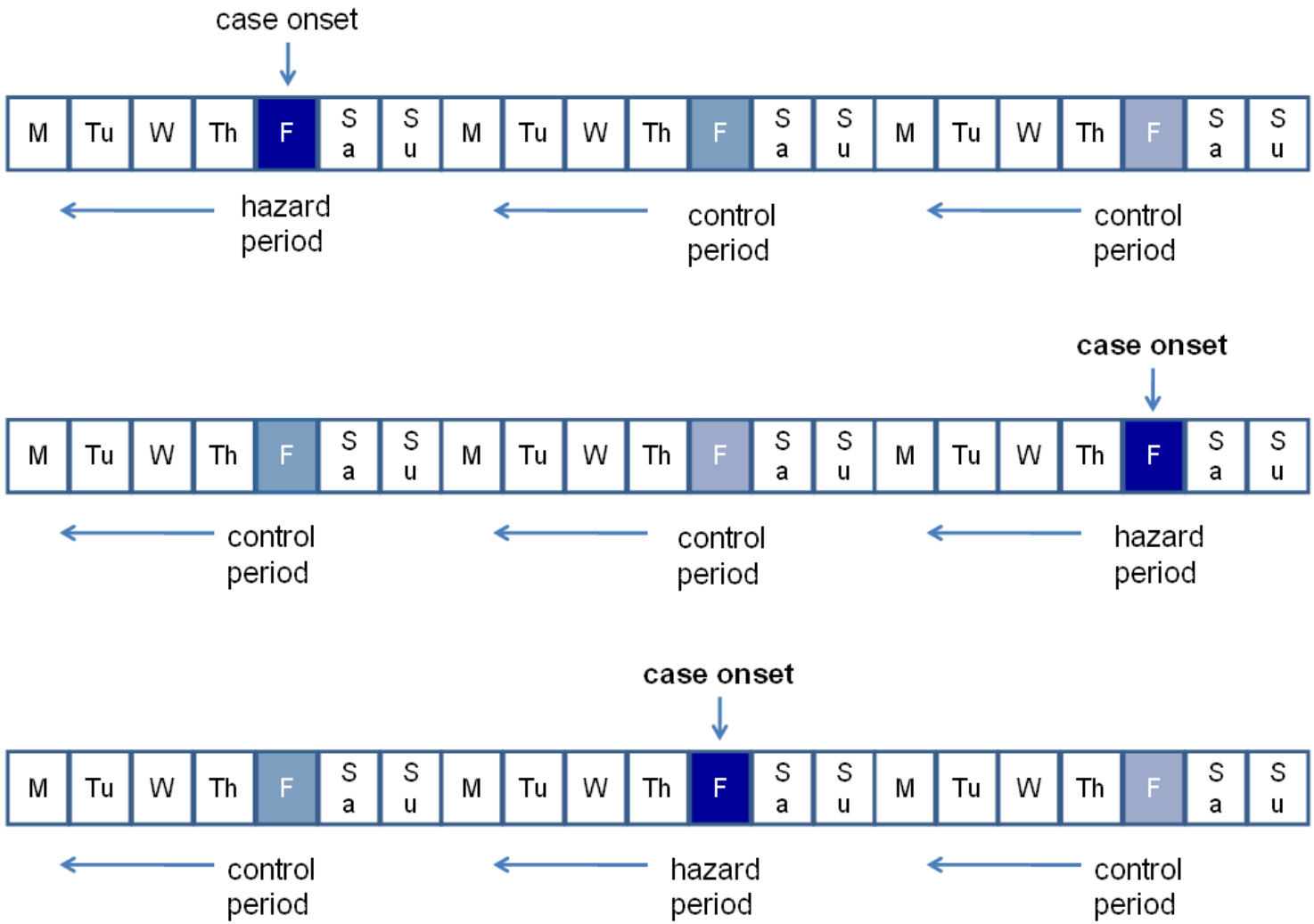



Source: AS Siraj et al., *Science* 2014.

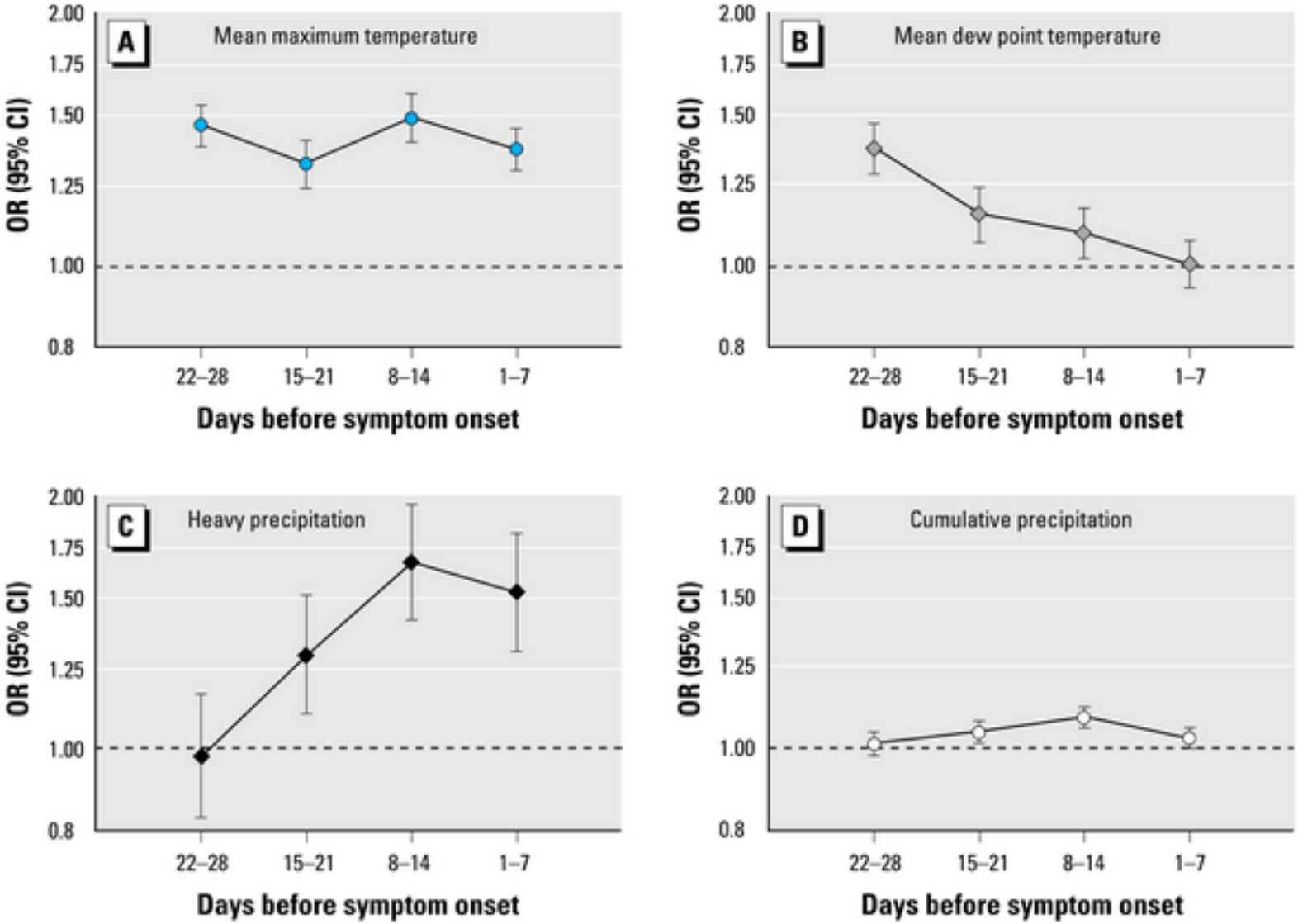
# West Nile Virus Infection




*[J. Soverow et al., Environmental Health Perspectives, 2009]*




**Supplementary Figure:** Schematic diagram of control selection strategy for case-crossover study. Each row represents a 3-week time block. Hazard and control periods (matched by day-of-week) are selected from the 3-week time block, resulting in random directionality of control selection.




Soverow J, et al. Environmental Health Perspectives 2009.

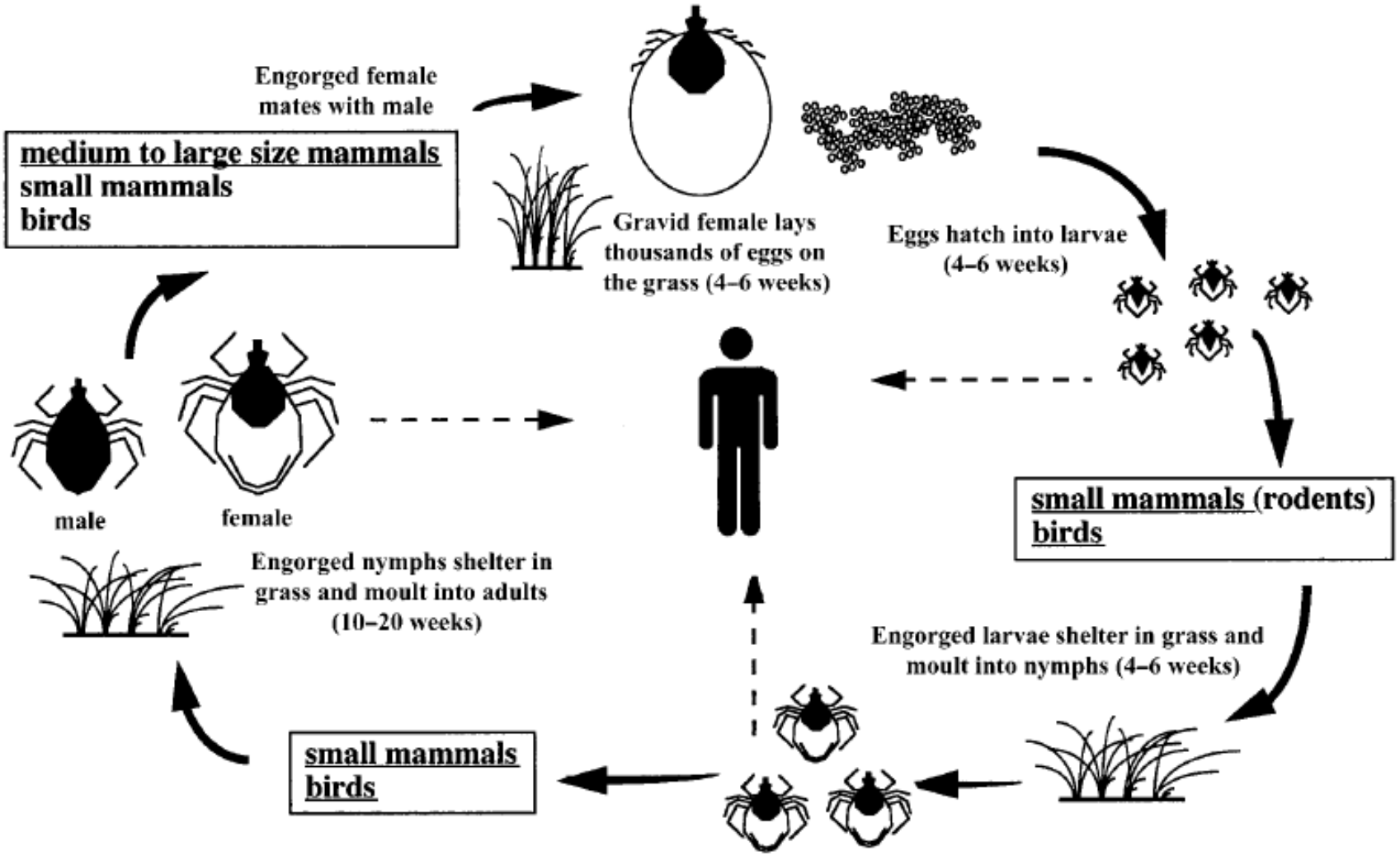
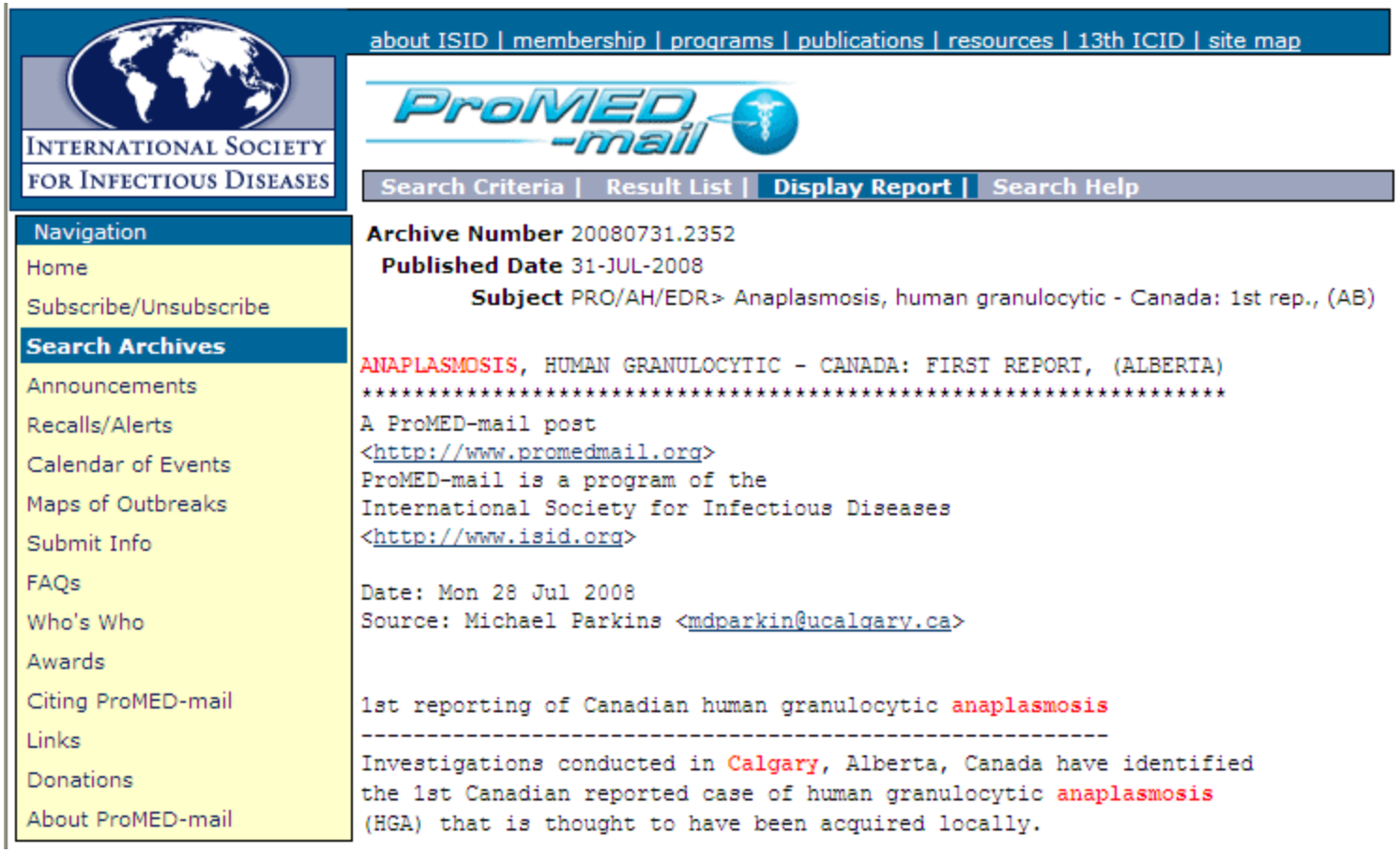



**Figure 6.** Life cycle of *Ixodes ricinus*. Hosts are listed in boxes; humans are potential hosts.

**[Source: Parola P and Raoult D. Clin Infect Dis 2001. 32(6): 897-928]**

# ProMed, July 31, 2008



about ISID | membership | programs | publications | resources | 13th ICID | site map

INTERNATIONAL SOCIETY FOR INFECTIOUS DISEASES

ProMED-mail

Search Criteria | Result List | Display Report | Search Help

Navigation
Home
Subscribe/Unsubscribe
Search Archives
Announcements
Recalls/Alerts
Calendar of Events
Maps of Outbreaks
Submit Info
FAQs
Who's Who
Awards
Citing ProMED-mail
Links
Donations
About ProMED-mail

**Archive Number** 20080731.2352
**Published Date** 31-JUL-2008
**Subject** PRO/AH/EDR> Anaplasmosis, human granulocytic - Canada: 1st rep., (AB)

ANAPLASMOSIS, HUMAN GRANULOCYTIC - CANADA: FIRST REPORT, (ALBERTA)
**********
A ProMED-mail post
<http://www.promedmail.org>
ProMED-mail is a program of the
International Society for Infectious Diseases
<http://www.isid.org>

Date: Mon 28 Jul 2008
Source: Michael Parkins <mdparkin@ucalgary.ca>

1st reporting of Canadian human granulocytic anaplasmosis
---
Investigations conducted in Calgary, Alberta, Canada have identified
the 1st Canadian reported case of human granulocytic anaplasmosis
(HGA) that is thought to have been acquired locally.

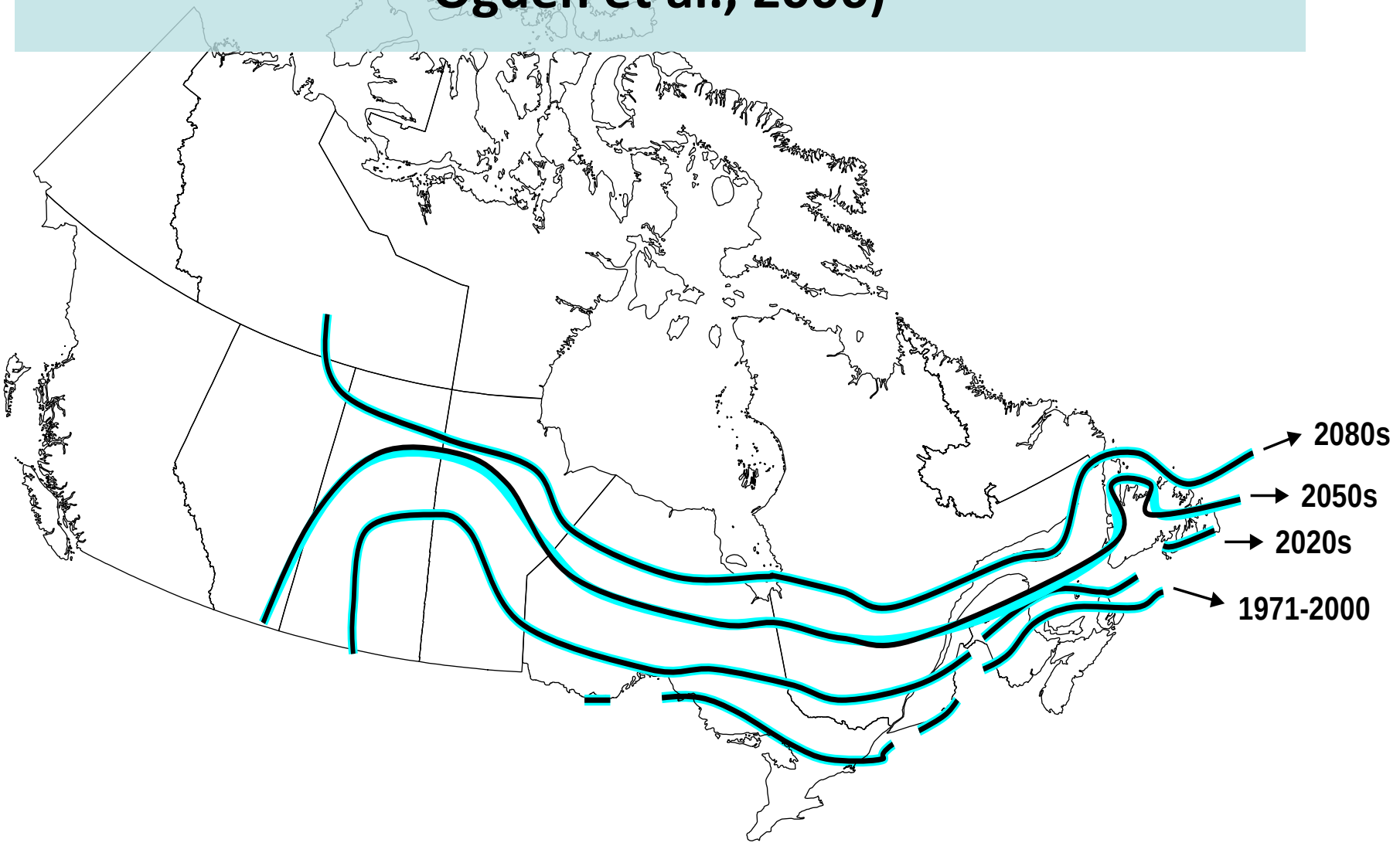
# ProMed, July 31, 2008

**1st reporting of Canadian human granulocytic anaplasmosis**

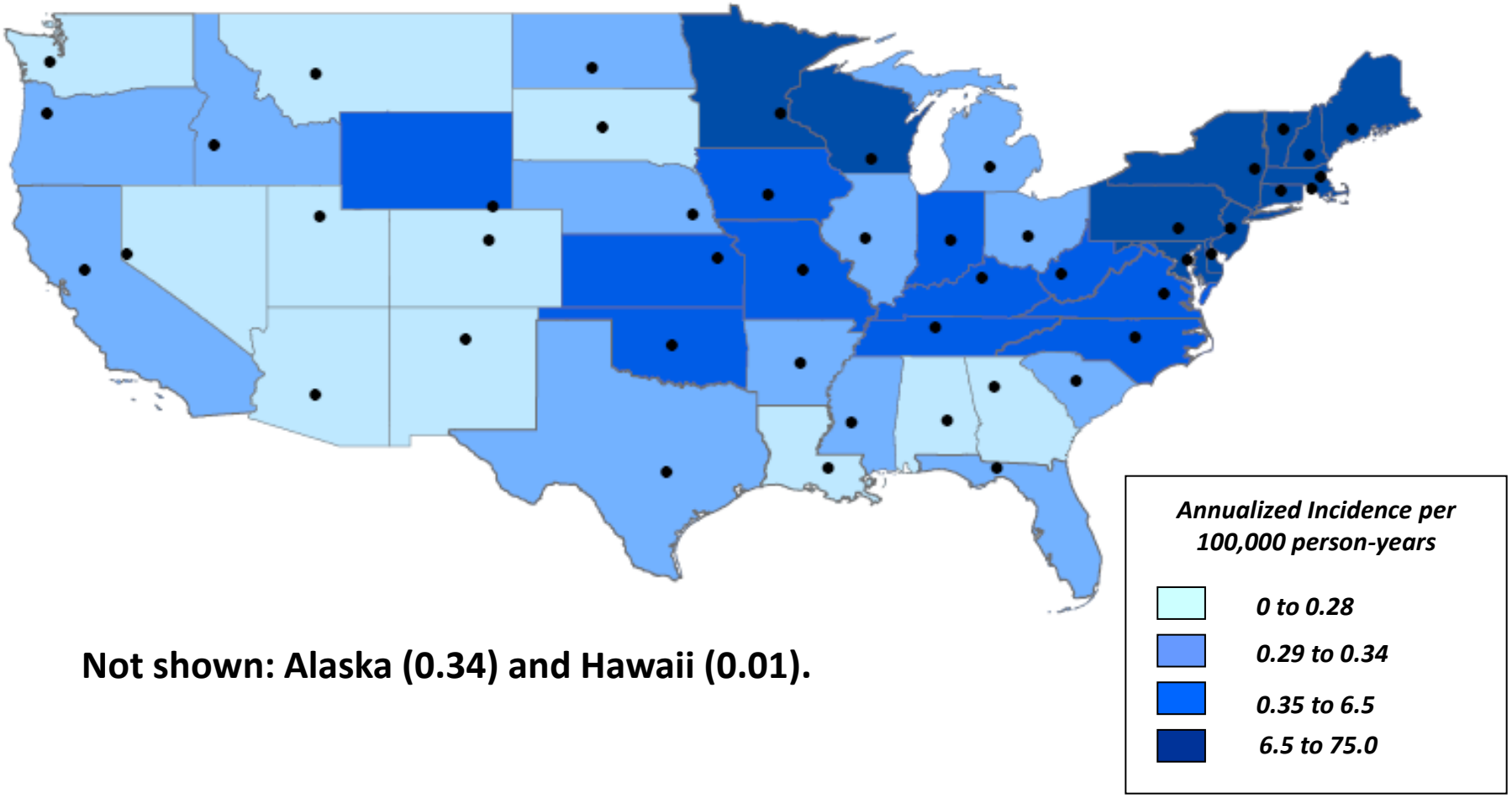
---

Investigations conducted in Calgary, Alberta…have identified the 1st Canadian reported case of human granulocytic anaplasmosis (HGA) that is thought to have been acquired locally. An 82-year-old man was admitted to a local hospital with fever and progressive confusion…A fully engorged *Ixodes* tick was identified on the patient during his 2nd day of hospitalization. Laboratory findings revealed leukopenia… thrombocytopenia, and increased liver enzymes…Peripheral blood smears revealed intracytoplasmic inclusions within granulocytes consistent with morulae…A whole blood PCR confirmed the presence of *Anaplasma phagocytophilum*. With the addition of doxycycline to his treatment regimen the patient made a full recovery. **He had not traveled outside of the city of Calgary in many years.** His tick(s) were thought to have been acquired during repeated forays into local wooded recreational areas.

# Model-derived temperature limits for *Ixodes scapularis* establishment in Canada (modified from Ogden et al., 2006)



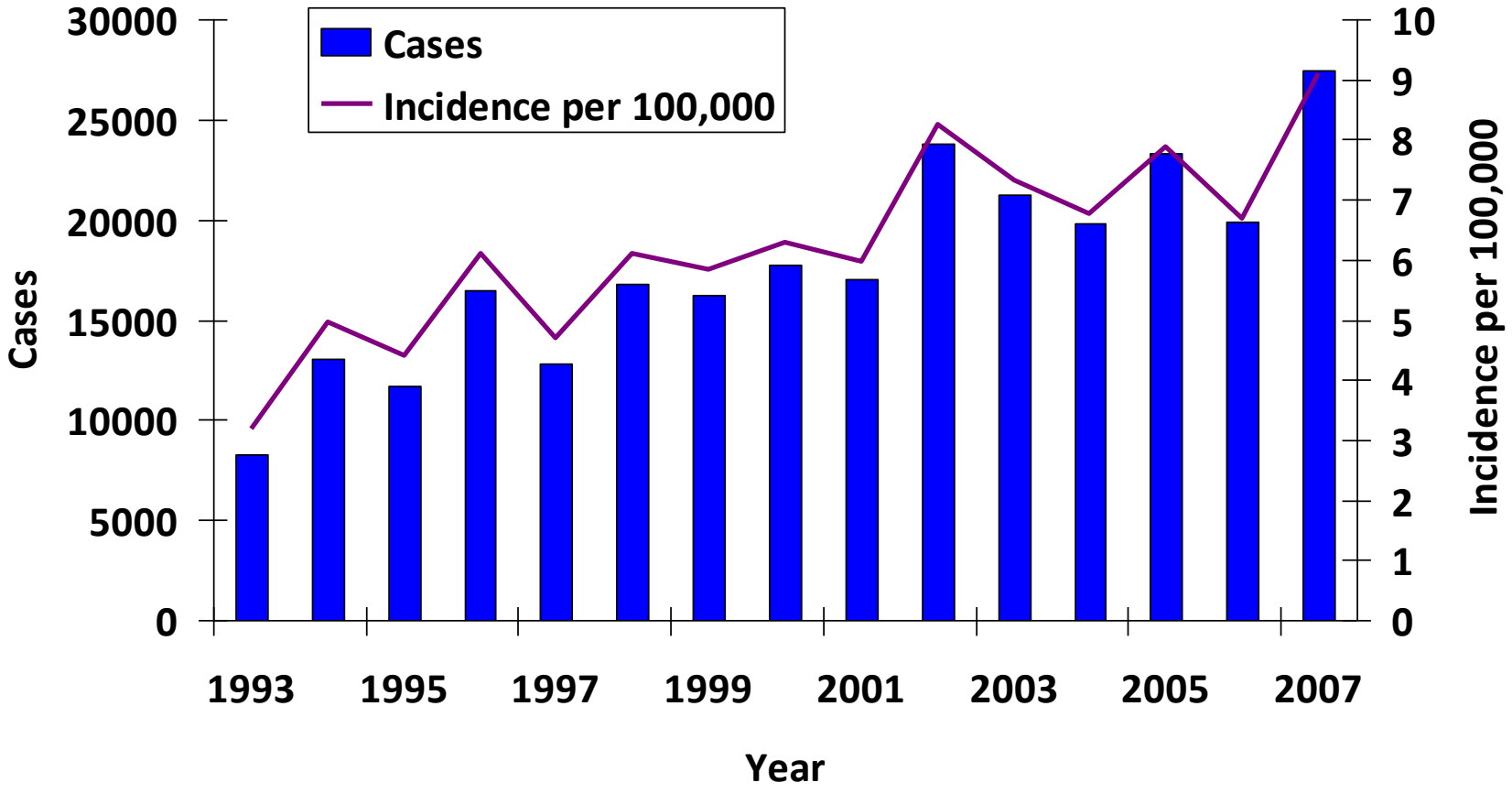
# *Lyme Disease Risk Quartiles, 1993-2007*




**Not shown: Alaska (0.34) and Hawaii (0.01).**

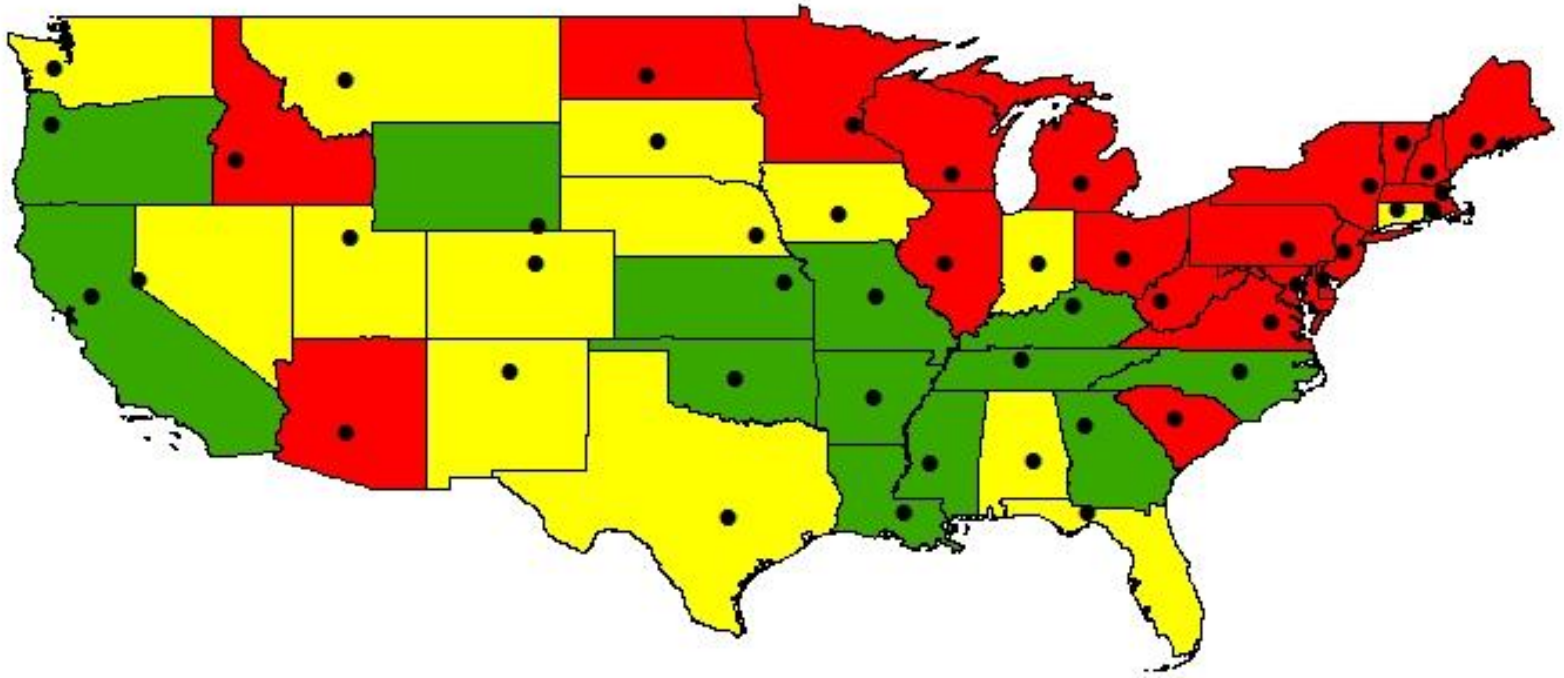
***[A. Tuite, A.L. Greer and D. Fisman, CMAJ Open 2013]***

# *Overall LD Incidence, U.S., 1993-2007*



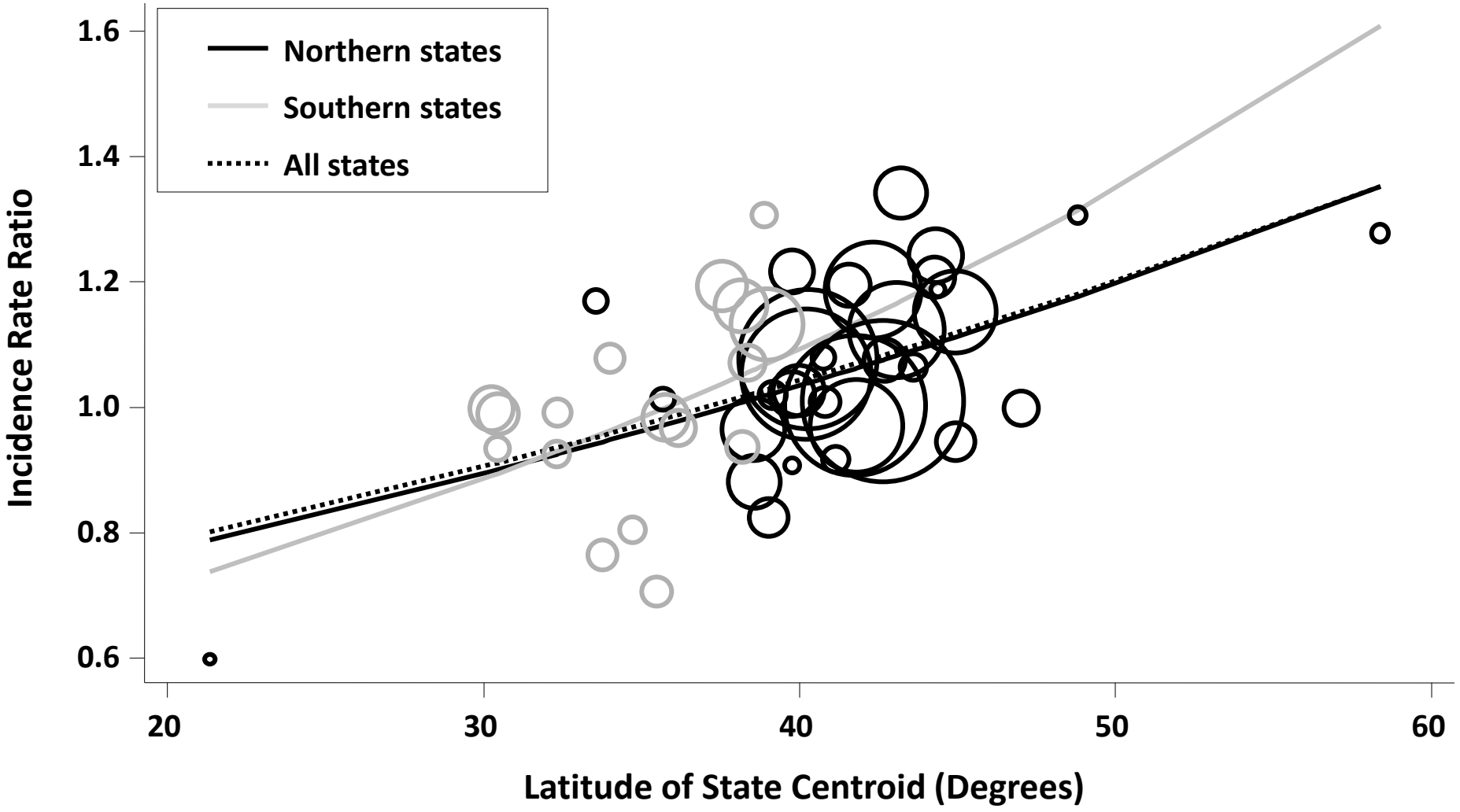

*[A. Tuite, A.L. Greer and D. Fisman, CMAJ Open 2013]*

# *Changes in Lyme Disease Risk in U.S., 1993 to 2007*




**Not shown: Alaska (IRR 1.28, 95% CI 1.15 to 1.42) and Hawaii (IRR 0.60, 95% CI 0.28 to 1.23)**

***[A. Tuite, A.L. Greer and D. Fisman, CMAJ Open 2013]***




*[A. Tuite, A.L. Greer and D. Fisman, CMAJ Open 2013]*

# El Niño Southern Oscillation: A Useful Model?

- Periodic thermal inversion in Pacific Ocean.
- Irregularly timed, ENSO effects:
  - Extreme weather events, heavy precipitation, elevated temperatures.
- Natural experiment that provides insight into future dimensions of climate change?
  - Relatively rare, so may need to evaluate *indices*, rather than “El Niño years”.

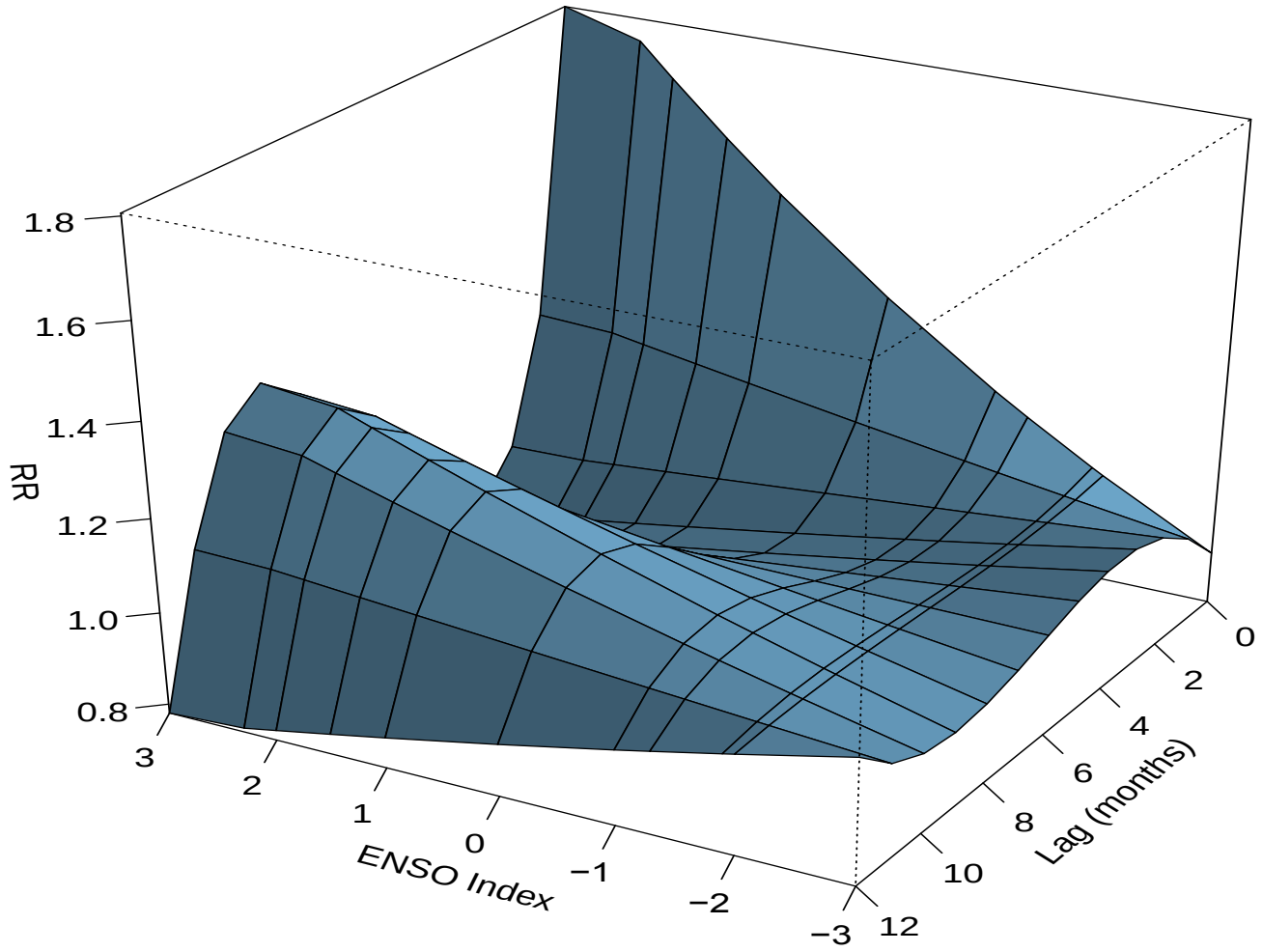
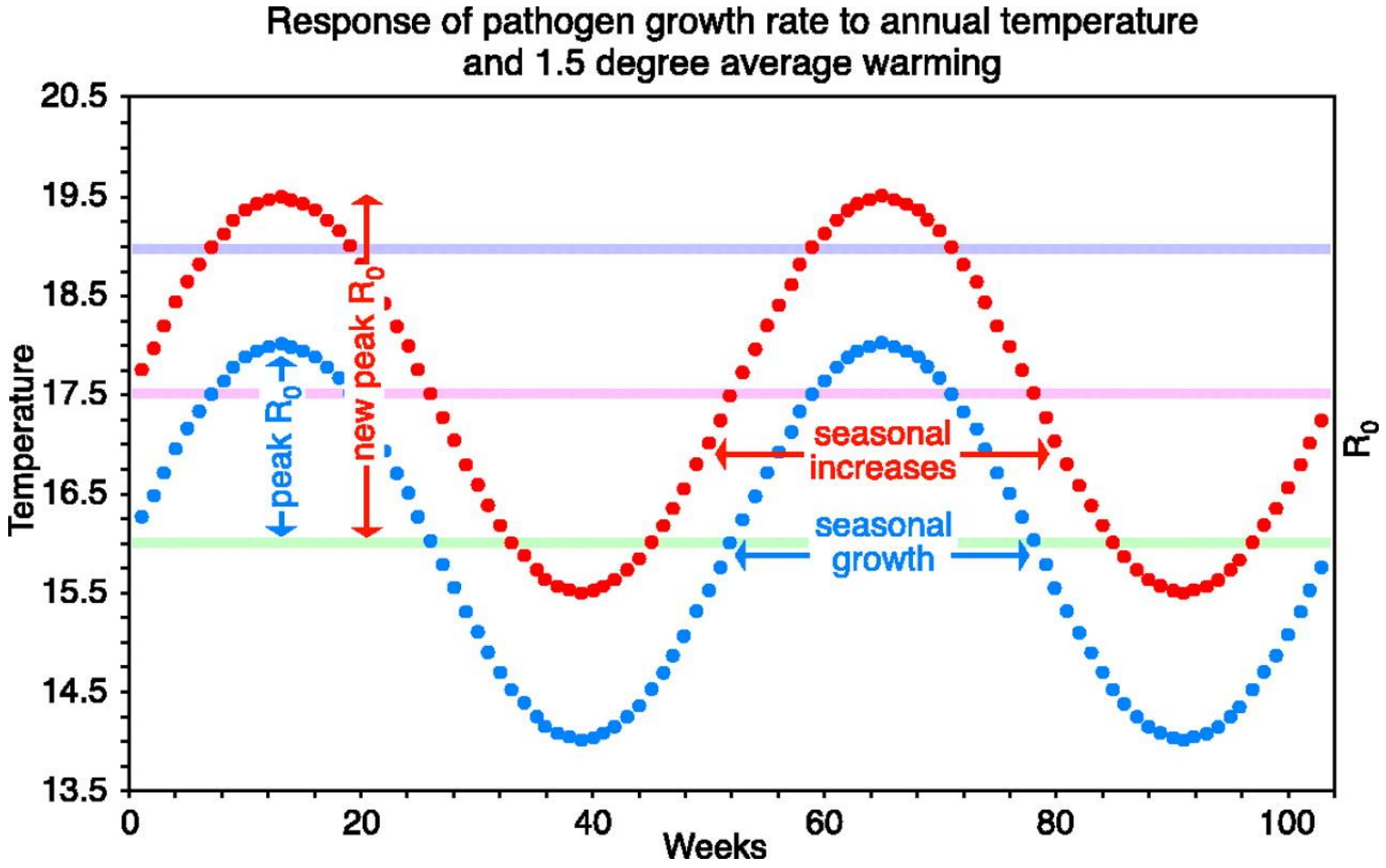



**Figure 3:** Graphical representation of distributed lag model of vectorborne disease risk in the NHDS dataset, and ENSO activity based on the multivariable ENSO index (MEI). Two peaks in risk (at 0 and 10 month lags) are seen, consistent with the biology of most vectorborne diseases. Cumulative 12 month relative risk for MEI = 2.5 is 2.63 (95% CI 1.39 to 4.97).

**Table 1.** Overall relative risk estimates (for all lags) of hospitalization for vector-borne disease in the NHDS dataset, 1970-2007, generated by a distributed lag non-linear model.

| ENSO Index Value | Relative Risk | 99% Confidence Interval |
|---|---|---|
| -2.1 (minimum observed value, referent) | 1.00 | |
| -1.3 | 1.18 | 1.06-1.32 |
| 1.5 | 2.13 | 1.30-3.15 |
| 2.5 (maximum observed value) | 2.63 | 1.39-4.97 |

# *The Physical Environment and Disease Transmission*

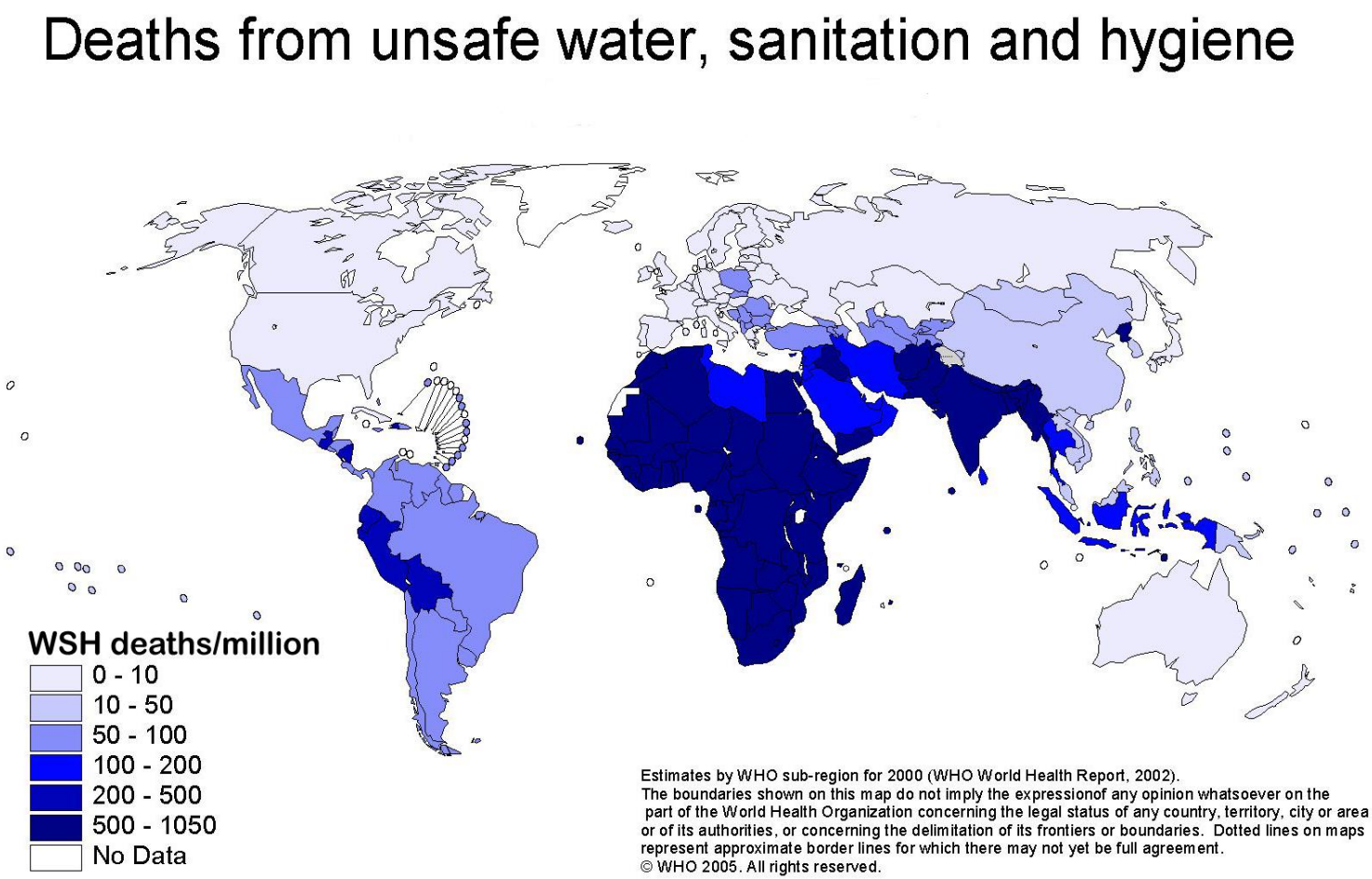



**Source: Harvell CD, Mitchell CE, Ward JR, et al. Climate warming and disease risks for terrestrial and marine biota. Science. 2002 Jun 21;296(5576):2158-62.**

# *Water- and Foodborne Diseases*

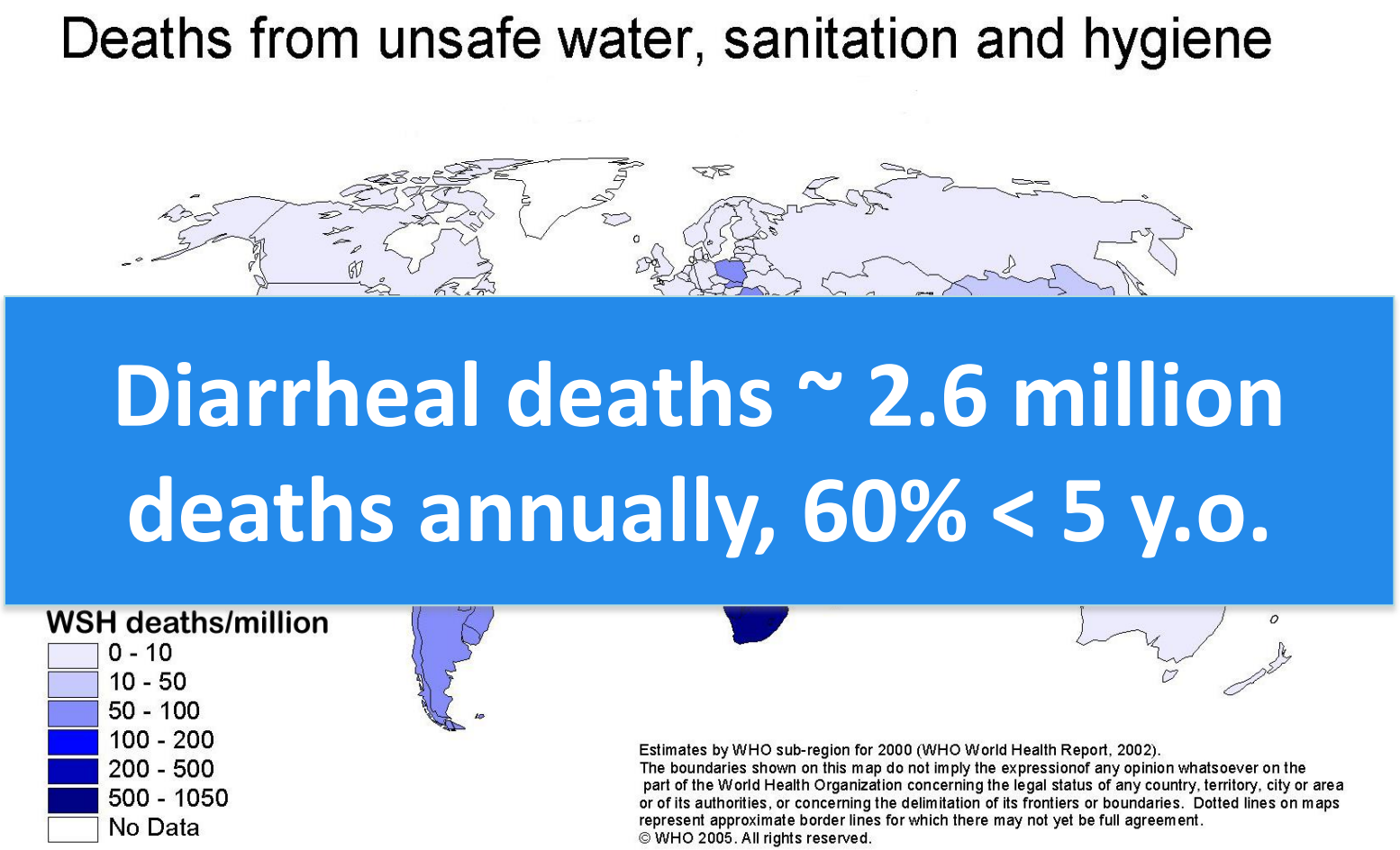
- An important source of morbidity in North America
  - Viral, bacterial and protozoan agents of gastroenteritis (e.g. *Salmonella* and *Shigella* species and toxin-elaborating *E-coli).*
    - Marked summertime (bacterial and protozoan pathogens) and wintertime (norovirus, rotavirus) seasonality.
  - Pneumonic pathogens (e.g. *Legionella* species)
- Large waterborne disease outbreaks have been linked to extreme precipitation events despite sophisticated water treatment systems (Charron et al., 2004; MacKenzie et al., 1994)

# The Bad (Awful, Actually) News




[Source: http://www.who.int/heli/risks/water/en/wshmap.pdf]

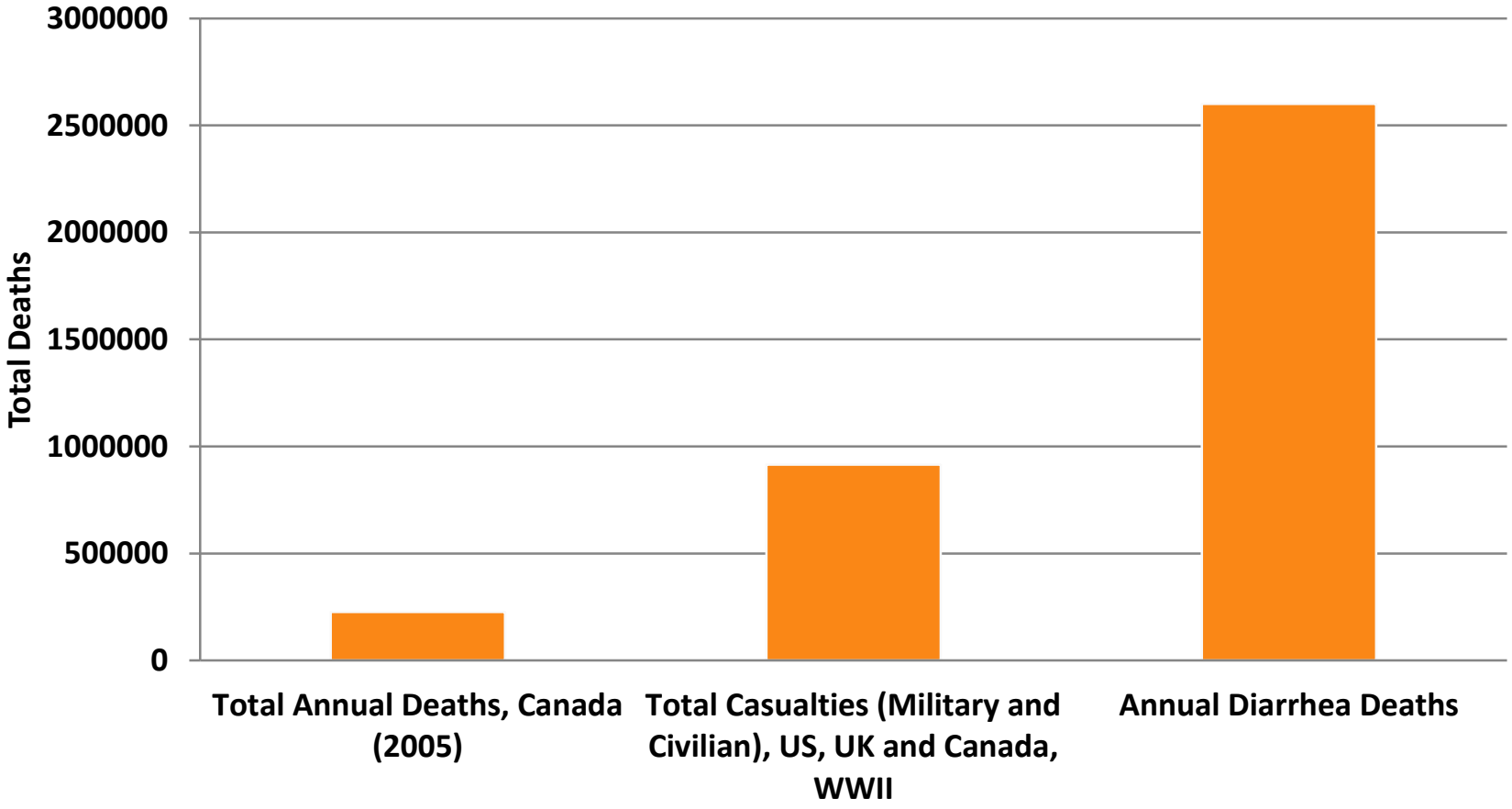
# The Bad (Awful, Actually) News




**Diarrheal deaths ~ 2.6 million deaths annually, 60% < 5 y.o.**

[Source: http://www.who.int/heli/risks/water/en/wshmap.pdf]

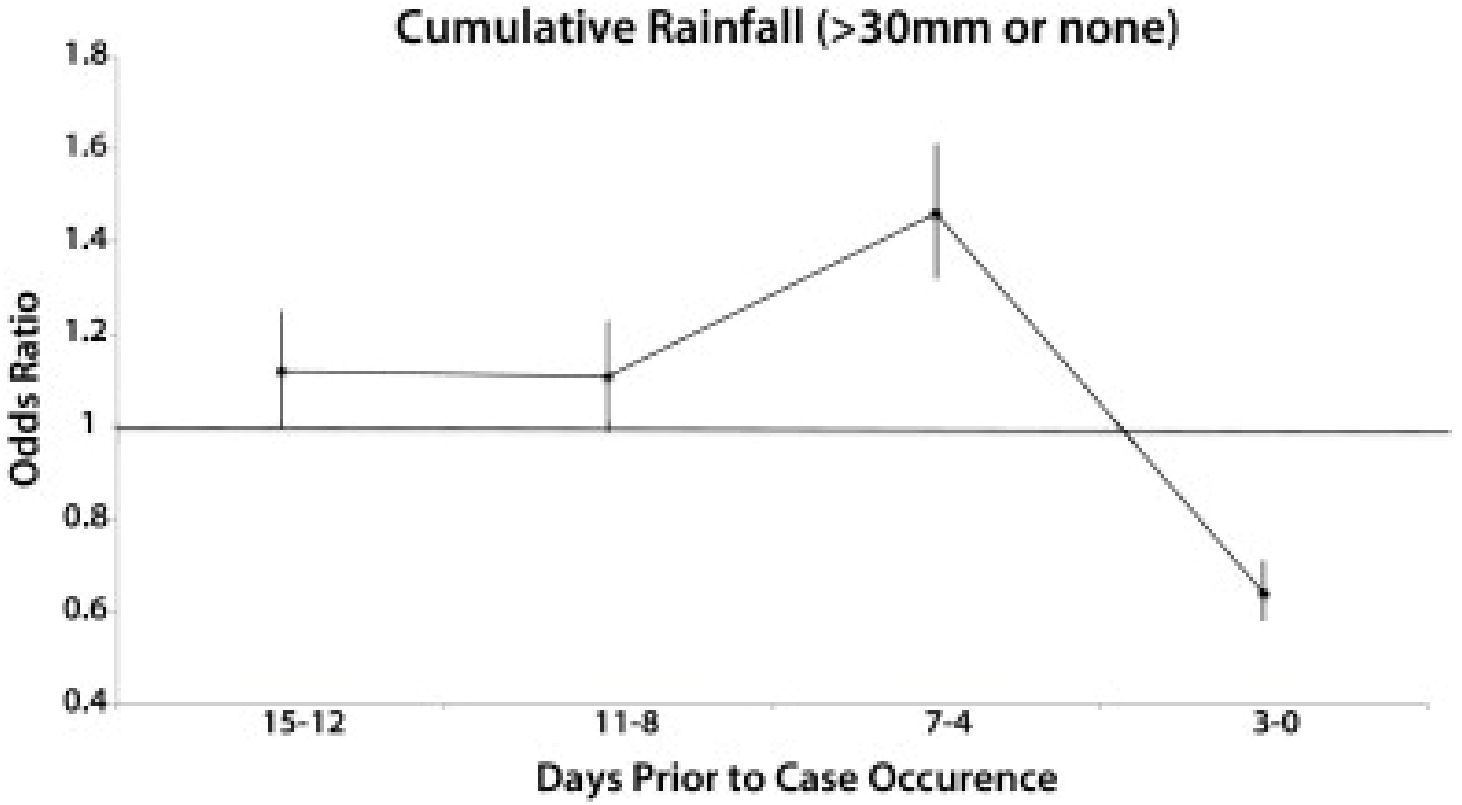
# What Does 2.6 Million Deaths Look Like?



# Toilets Can, And Do, Fly

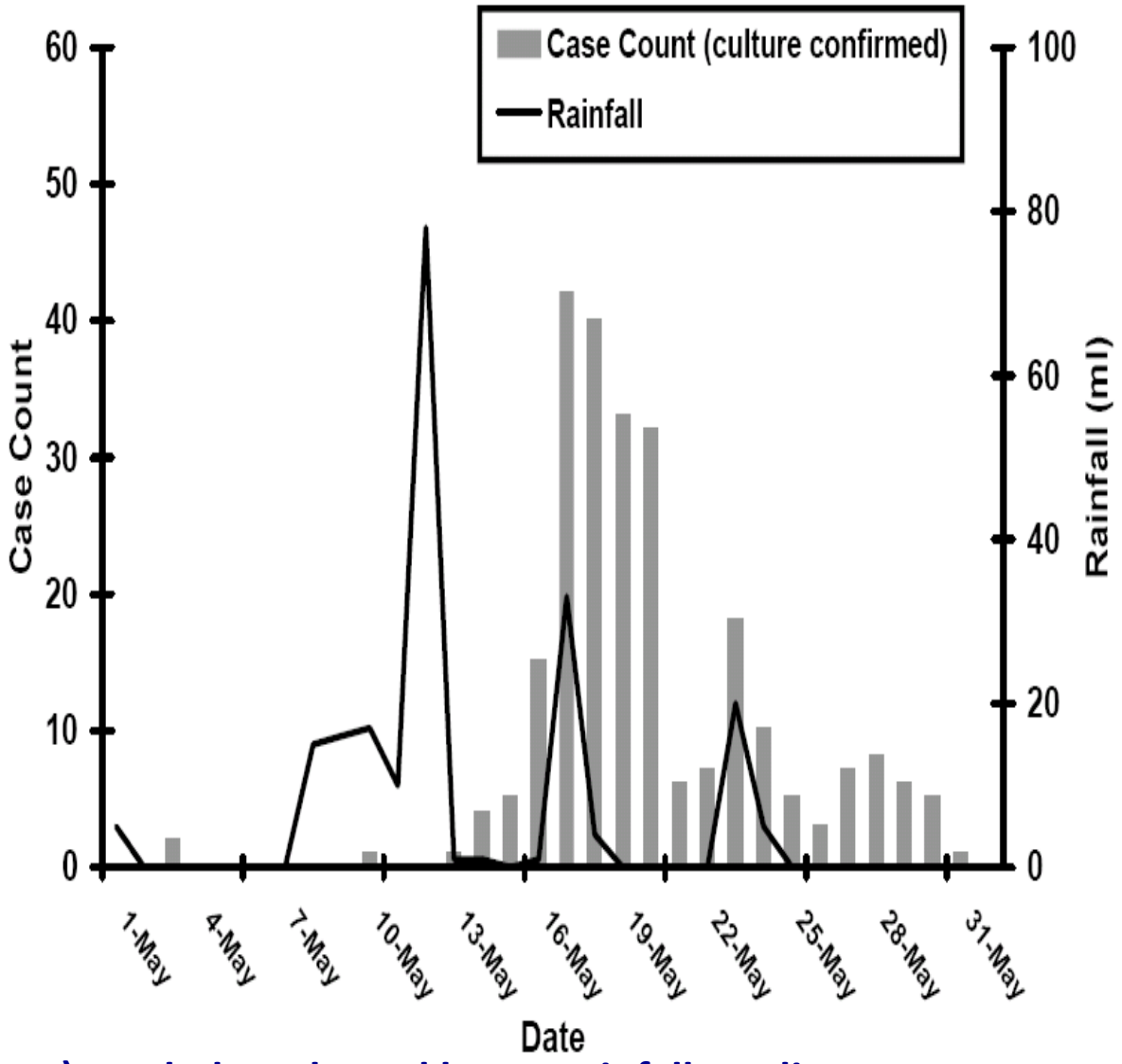
Flying toilets used to fashion a makeshift road, Cap-Hatien, Haiti. Remi Kaupp, Wikimedia Commons. Source: http://en.wikipedia.org/wiki/File:Solid_waste_used_to_build_a_road.jpg

# Cholera and Rainfall: Haiti, 2010




Source: Eisenberg M et al., *Epidemics* 2013

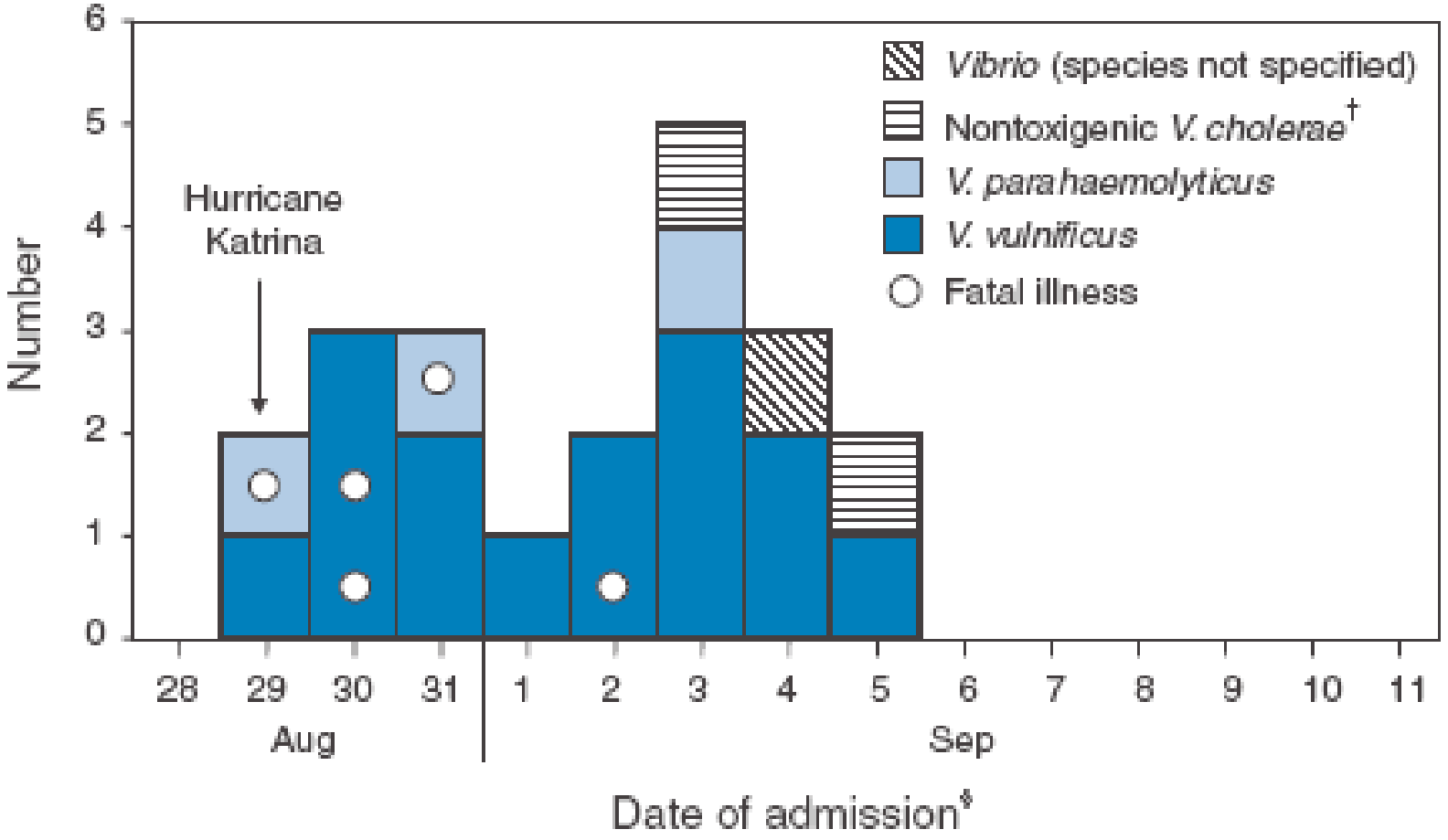
**Association between extreme precipitation and waterborne disease outbreaks (modified from Auld et al., 2004)**




**Also Nichols et al. (1910-1999, UK): Both drought and heavy rainfall predict gastro outbreaks (J Water Health 2009).**

(Greer et al., Figure 3)

# Hurricane Katrina

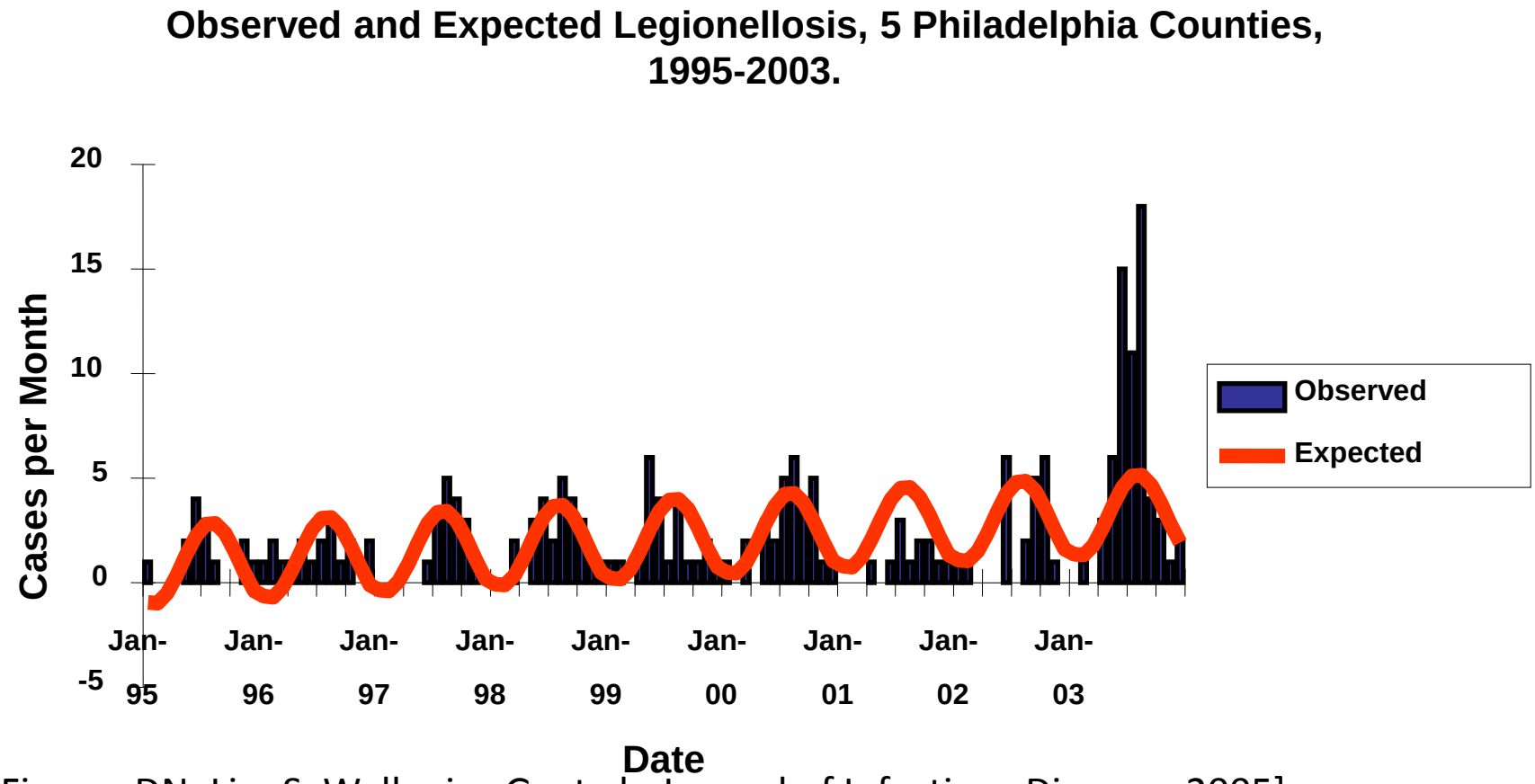



**[Source: U.S. CDC, MMWR September 23, 2005: 54(37);928-931. Available via the Internet at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5437a5.htm.**

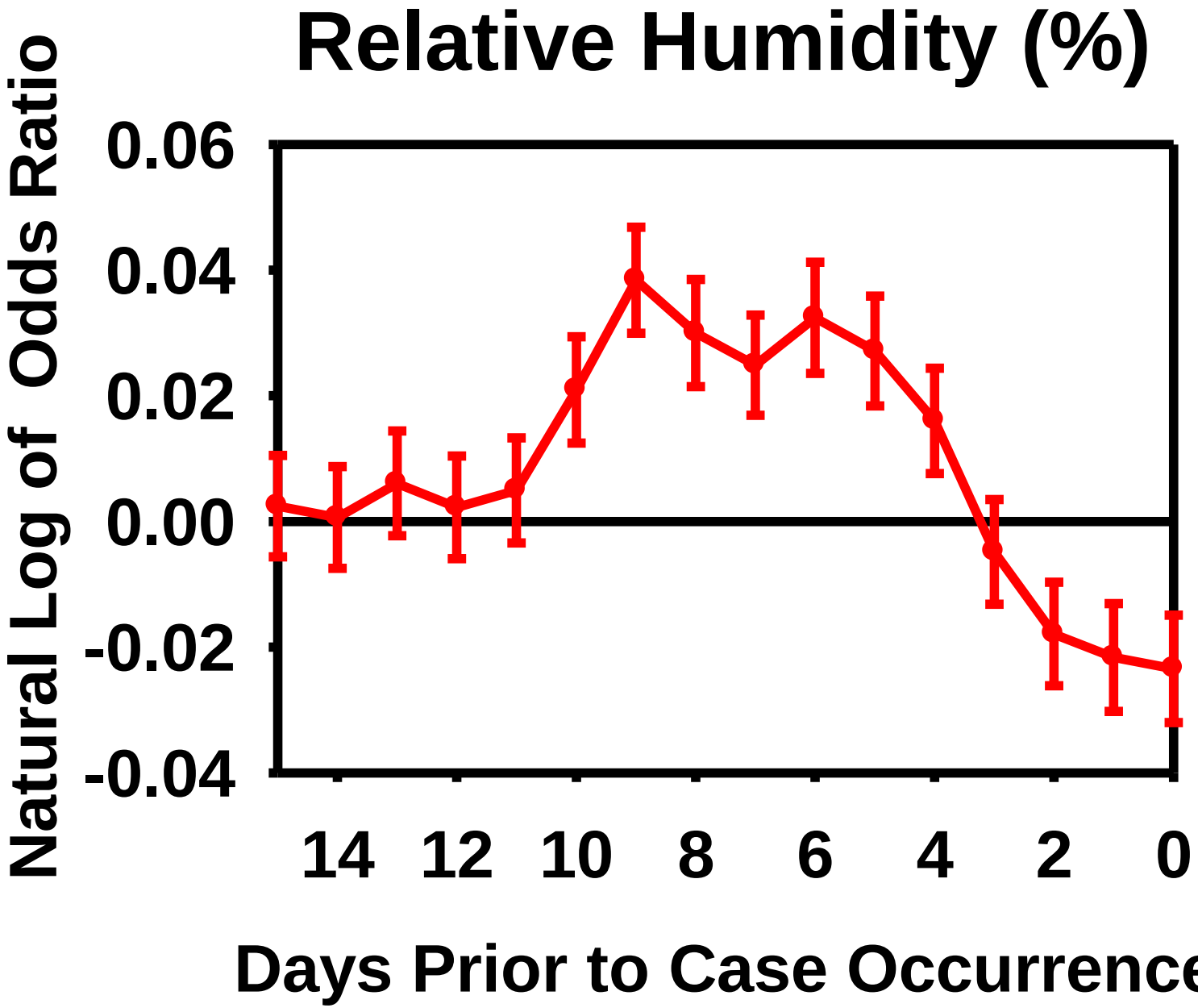
# Innoculation and Environmentally Abundant Pathogens

- Strength and frequency of extreme weather events (tornados, hurricanes, cyclones) projected to increase.
  - Generation of aerosols, inocculation via air- or waterborne debris.
- Severity of respiratory infection caused by ***B. pseudomallei*** increased following monsoon rains in northern Australia [Currie and Jacups, EID 2001].
- Infectious sequelae of South Asian tsunami in 2004: **Clostridial** infections, atypical **mycobacterial** infections of skin and soft tissues, **MDR GNR**.

# Legionellosis, Philadelphia

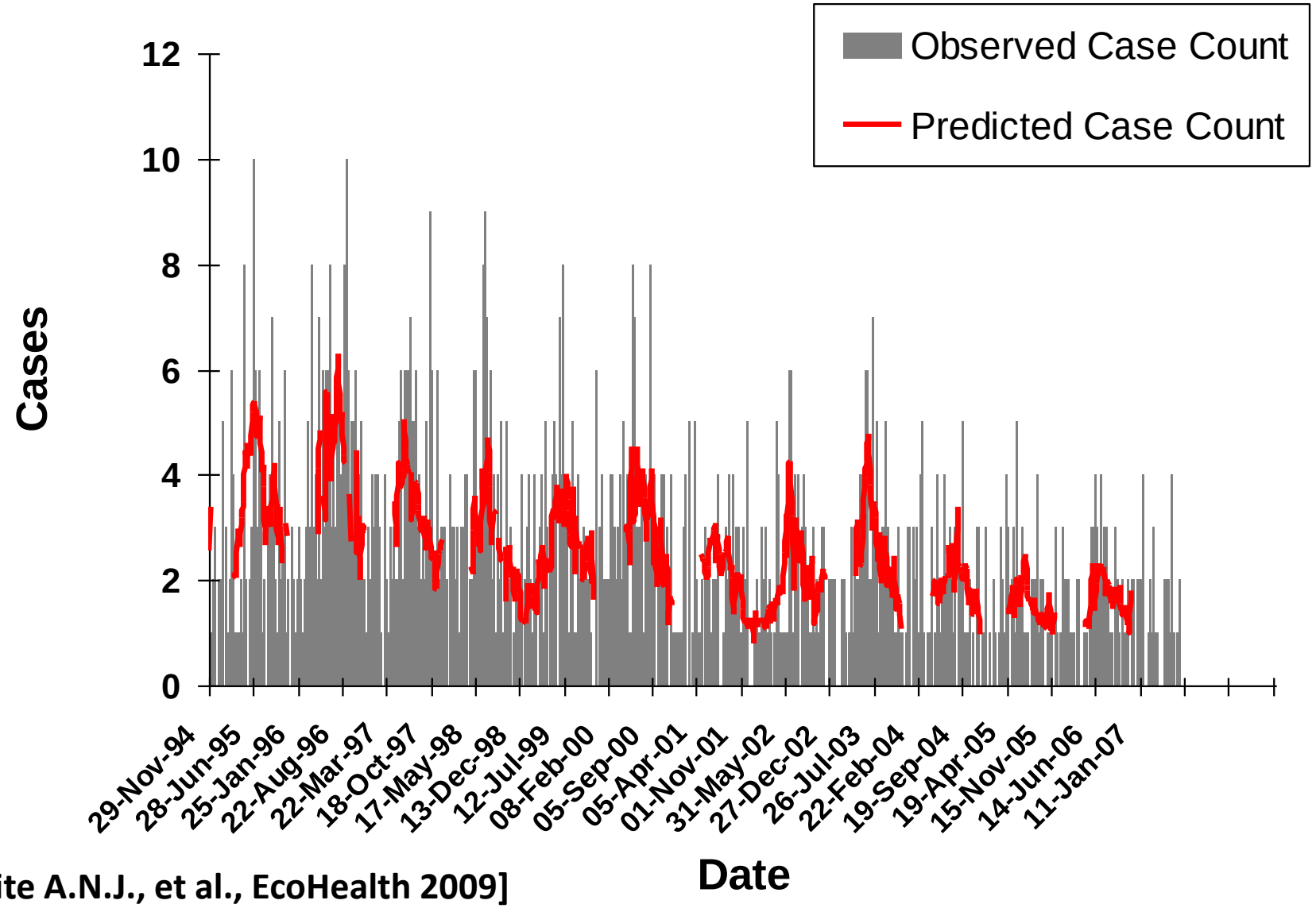



[Fisman DN, Lim S, Wellenius G, et al., Journal of Infectious Diseases 2005]



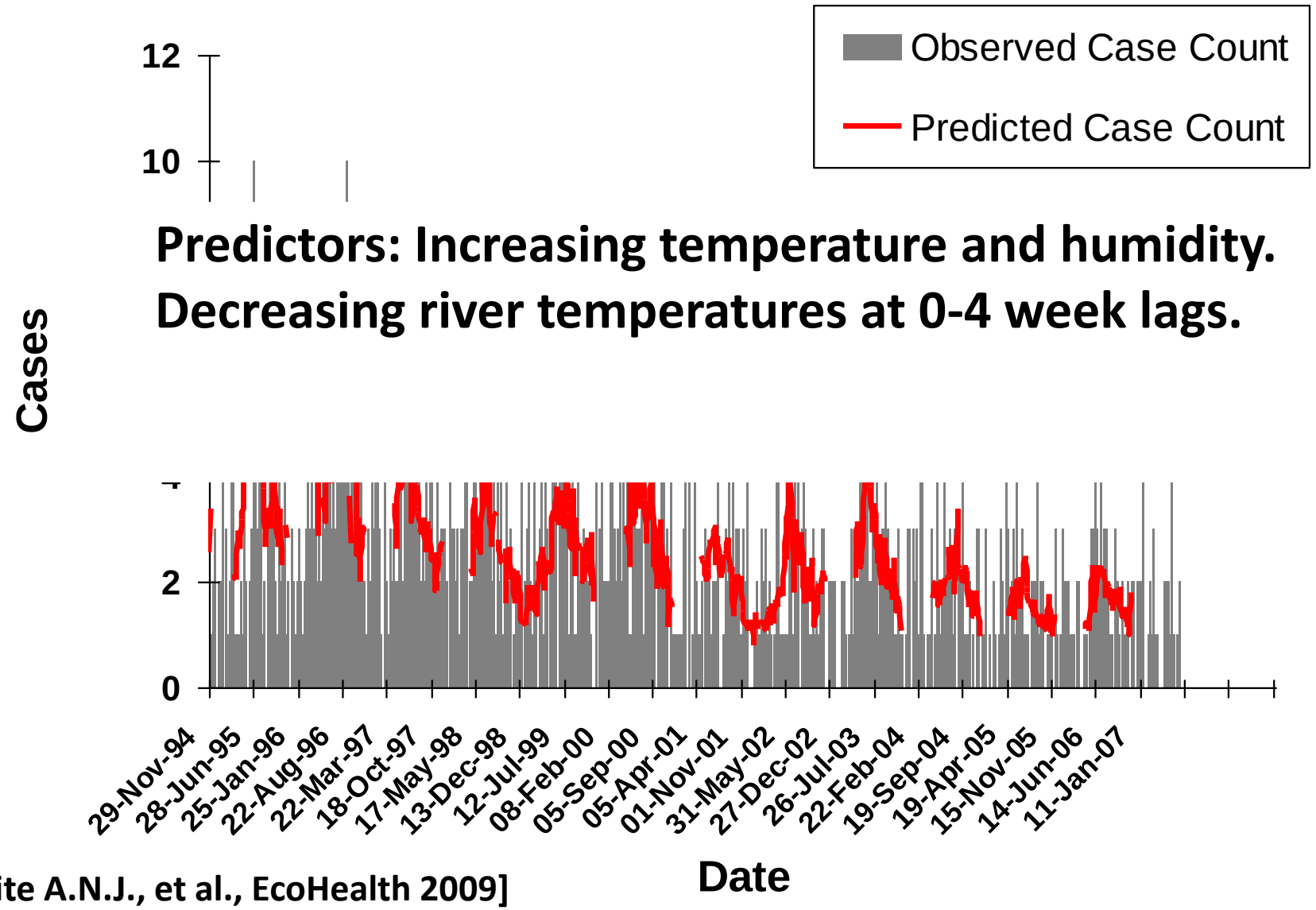

**Summary IRR for legionellosis per % increase in RH 6–10 days prior to case occurrence 1.076 (95% CI, 1.048–1.106).**

# *Campylobacteriosis, Philadelphia 1993-2007*



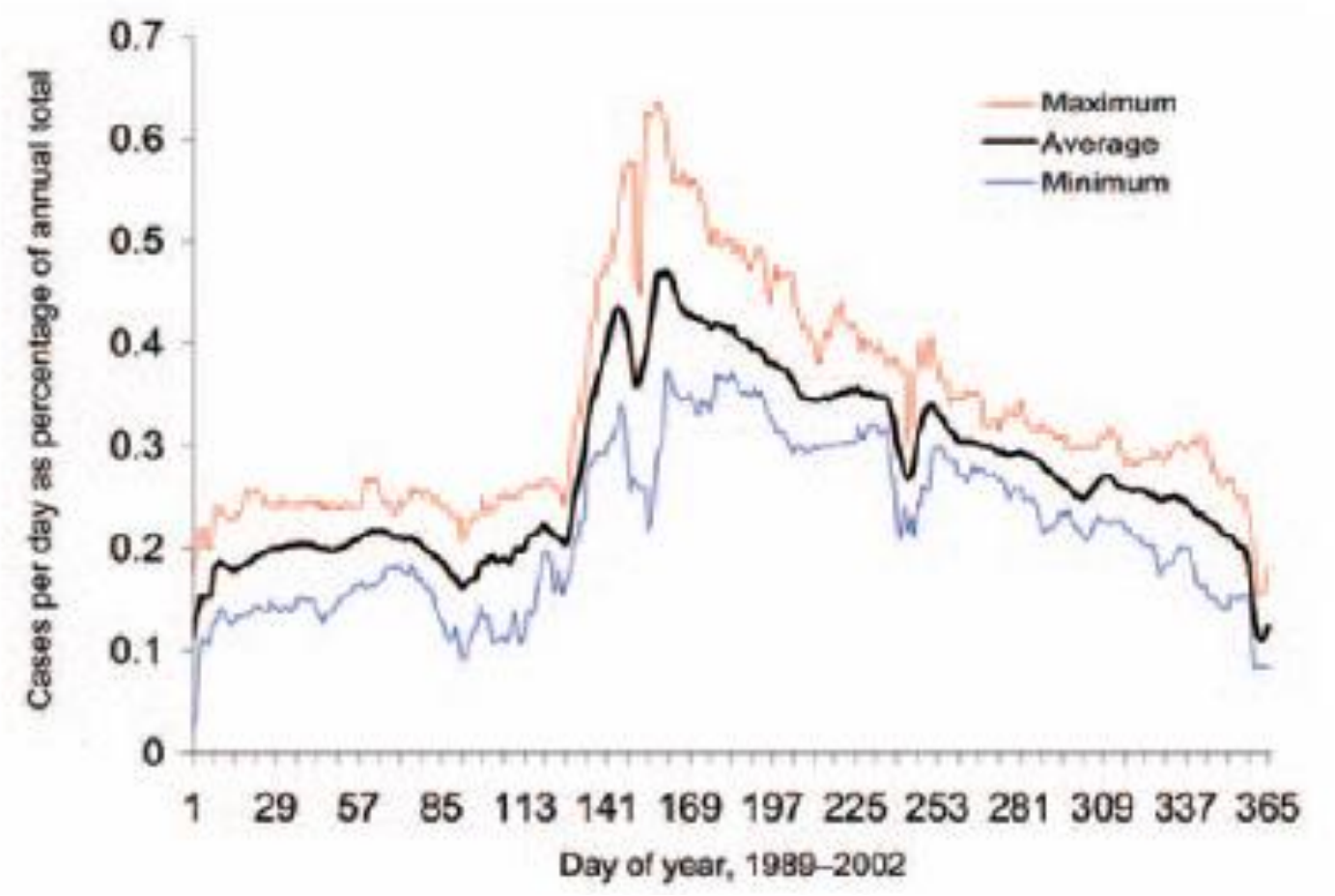

[White A.N.J., et al., EcoHealth 2009]

# *Campylobacteriosis, Philadelphia 1993-2007*



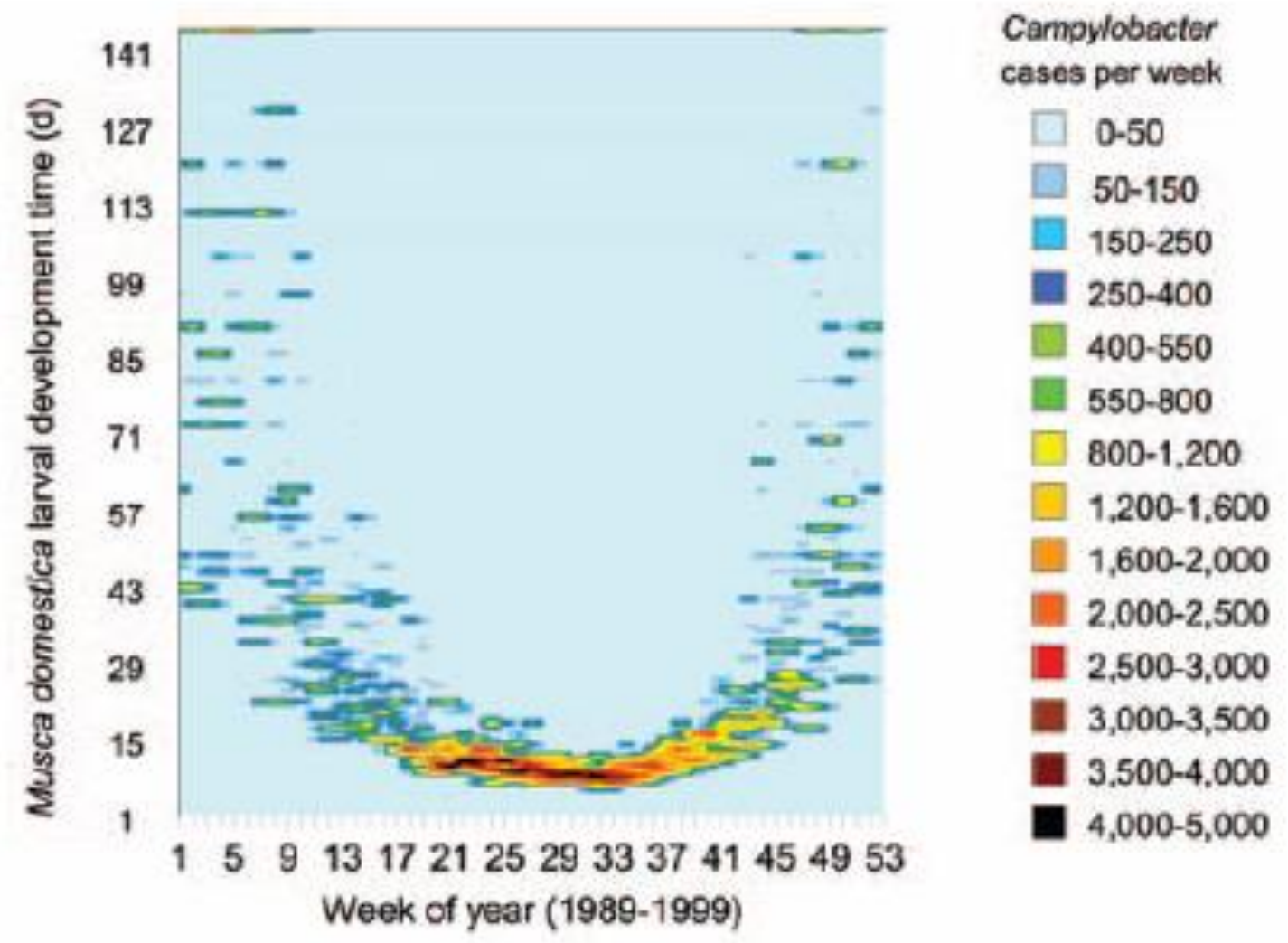

[White A.N.J., et al., EcoHealth 2009]

# *Campylobacteriosis and Flies*




**[Source: Nichols G, Emerging Infectious Diseases 2005; 11: 361-4]**

# *Campylobacteriosis and Flies*



# *Mitigation and Implications for Vulnerable Populations*

# Vulnerability and Climate Change

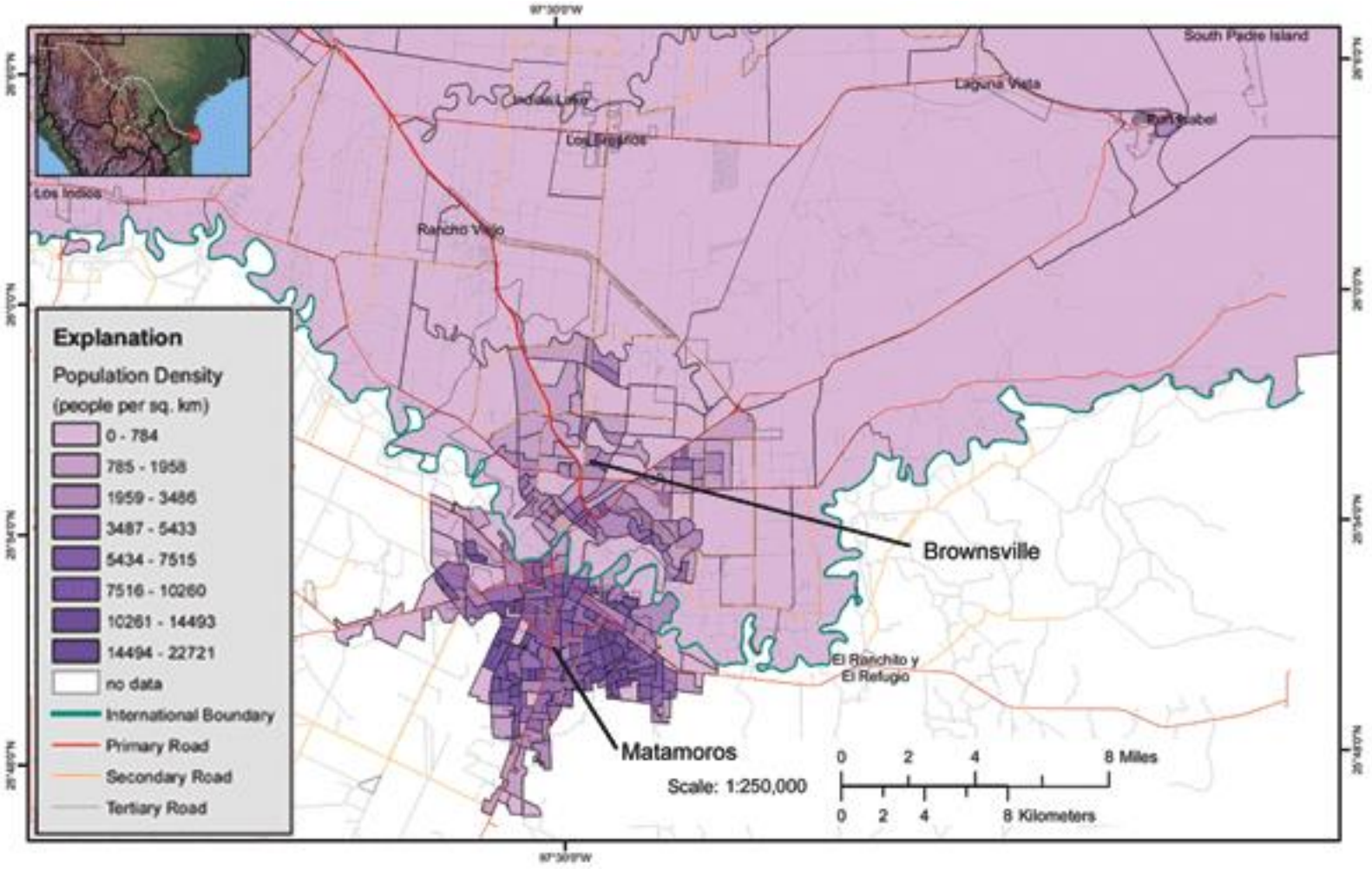
NIEHS
National Institute of Environmental Health Sciences

**Climate-Sensitive Health Outcomes and Particularly Vulnerable Groups**

| Health Outcome | Vulnerable Groups |
|---|---|
| **Heat Stress** | Elderly, chronic medical conditions, infants and children, pregnant women, urban and rural poor, outdoor workers |
| **Air Pollution Effects** | Children, pre-existing heart or lung disease, diabetes, athletes, outdoor workers |
| **Extreme Weather Events** | Poor, pregnant women, chronic medical conditions, mobility and cognitive constraints |
| **Water- and Foodborne Illness** | Immunocompromised, elderly, infants; |
| **Vectorborne Illness** | Children, pregnant women, outdoor workers |

Source: Dr. John Balbus, Institute of Medicine panel on IAQ and Climate Change, Washington, DC, June 7, 2010

# Mitigation: The Texas—Mexico Dengue Gap




Brunkard JM et al., Emerging Infectious Diseases 2007.

# Mitigation: The Texas—Mexico Dengue Gap

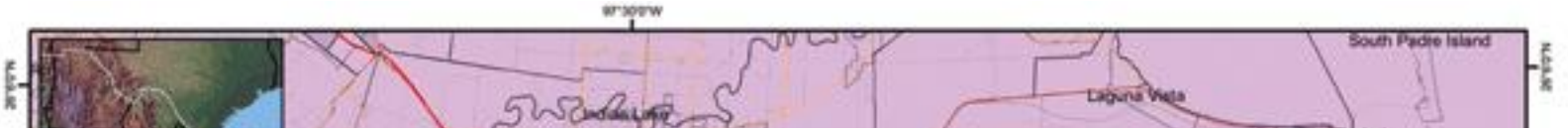



**Table 5.** Logistic regression results for serologic evidence of past dengue infection in Brownsville, Texas, and Matamoros, Mexico, 2004*

| Variable | Adjusted odds ratio | p value | 95% Confidence interval | Deff |
|---|---|---|---|---|
| Income ≤$100 | 2.59 | 0.000 | 1.58–4.26 | 0.92 |
| Missing income | 0.90 | 0.679 | 0.54–1.50 | 0.83 |
| Street drainage | 0.57 | 0.009 | 0.37–0.87 | 1.07 |
| Larval habitat | 2.35 | 0.008 | 1.26–4.41 | 1.00 |
| Air-conditioning | 0.58 | 0.014 | 0.38–0.89 | 1.04 |
| Intact screens | 1.35 | 0.111 | 0.93–1.95 | 0.90 |
| Store water | 1.62 | 0.079 | 0.95–2.76 | 1.19 |
| *Aedes aegypti* | 0.84 | 0.476 | 0.53–1.35 | 1.05 |
| Cross border, 3 mo | 0.90 | 0.581 | 0.62–1.31 | 0.93 |
| People/household | 1.06 | 0.300 | 0.95–1.19 | 1.31 |

*Missing data in independent variables (n = 22) did not significantly change prevalence of recent or past dengue infection (p>0.10) in the remaining 578 observations used in subsequent models. Deff, design effect, the ratio of variance between the survey design and simple random sampling.


Brunkard JM et al., Emerging Infectious Diseases 2007.

# Vulnerability and Climate Change

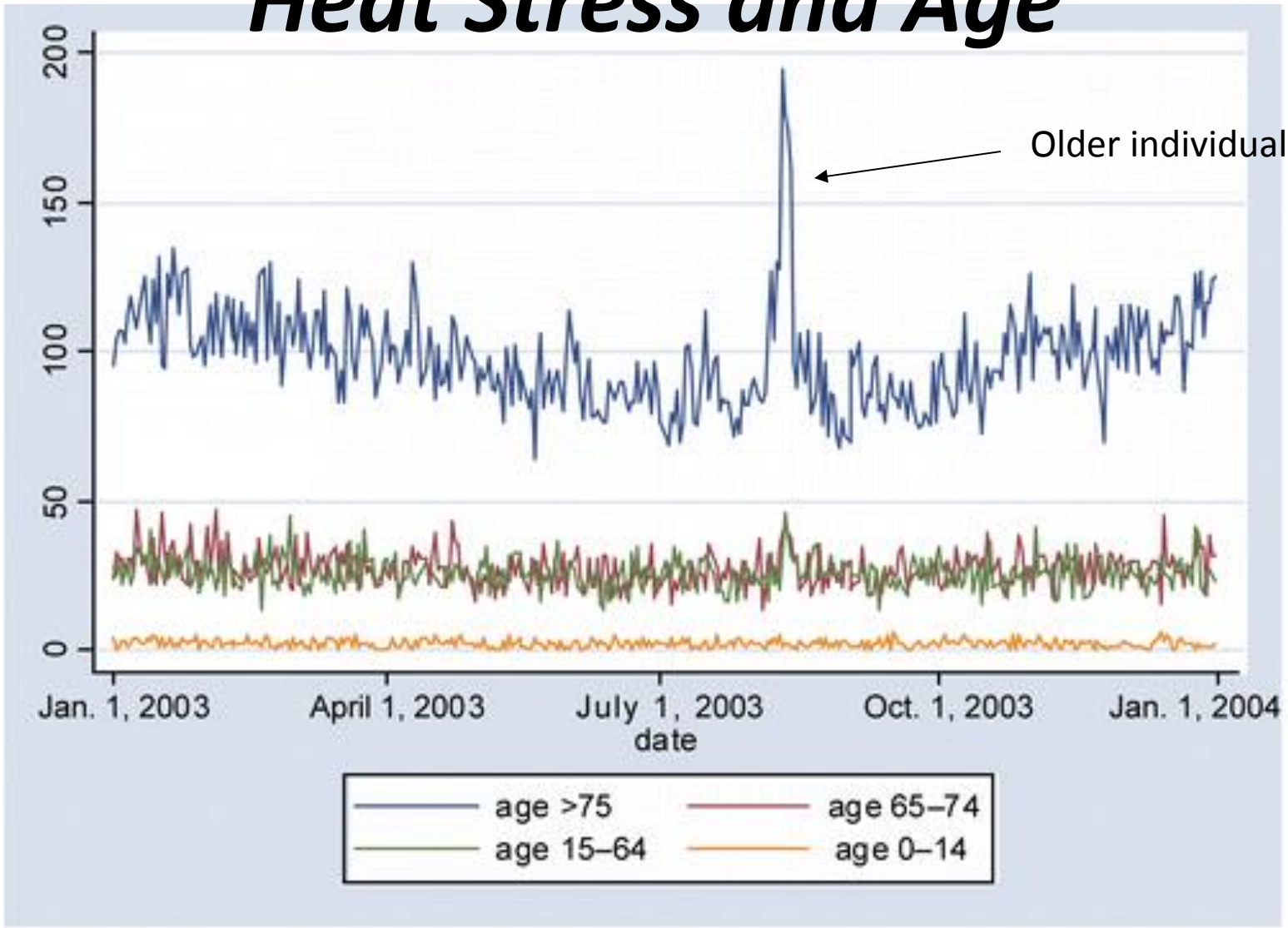
NIEHS
National Institute of Environmental Health Sciences

**Climate-Sensitive Health Outcomes and Particularly Vulnerable Groups**

| Health Outcome | Vulnerable Groups |
|---|---|
| **Heat Stress** | Elderly, chronic medical conditions, infants and children, pregnant women, urban and rural poor, outdoor workers |
| **Air Pollution Effects** | Children, pre-existing heart or lung disease, diabetes, athletes, outdoor workers |
| **Extreme Weather Events** | Poor, pregnant women, chronic medical conditions, mobility and cognitive constraints |
| **Water- and Foodborne Illness** | Immunocompromised, elderly, infants; |
| **Vectorborne Illness** | Children, pregnant women, outdoor workers |

Source: Dr. John Balbus, Institute of Medicine panel on IAQ and Climate Change, Washington, DC, June 7, 2010

# Heat Stress and Age




Kovats RS, Hajat S. 2008.
Annu. Rev. Public Health. 29:41–55

Summer 2003 London heatwave:
616 deaths (42% increase in mortality)

www.onehealthinitiative.com

# One Health initiative


Home page

About One Health

Mission Statement

One Health News

AVMA Task Force Report

One Health Newsletter

Publications

ProMED Outbreak Reports

Supporters

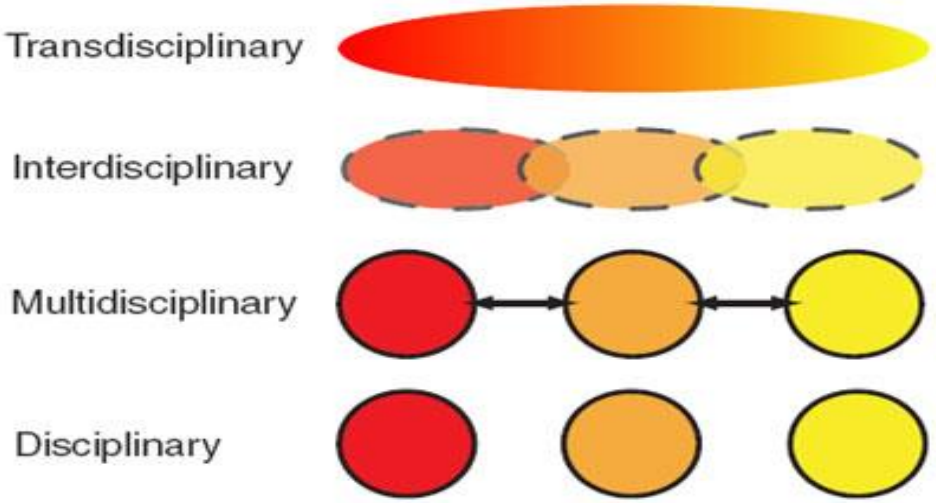
Supporter Endorsements


## One Health Initiative will unite human and veterinary medicine

The One Health Initiative, a movement to forge co-equal, all inclusive collaborations between physicians, veterinarians, and other scientific-health related disciplines, has been endorsed by various major medical organizations and health agencies, including the American Veterinary Medical Association, the American Medical Association, the American Society of Tropical Medicine and Hygiene, the American Society for Microbiology and the

# Moving Beyond the Disciplines

- A fully dimensional understanding of infectious disease reaches across scales
- Medicine and public health are enriched by insights from across the natural sciences and engineerin




Colon et al. 2008

**Table 1.** Modeling effort for selected zoonotic pathogens, organized by pathogen stage (see Fig. 1A) and number of published dynamical models. Abbreviations: EV, encephalitis virus; HF, hemorrhagic fever; BSE, bovine spongiform encephalopathy.

| Pathogen stage | Number of modeling studies | | | | |
|---|---|---|---|---|---|
| | 0 | 1 to 5 | 6 to 10 | 11 to 20 | >20 |
| II (Spillover only) | *Babesia microti*<br>*Bartonella henselae*<br>*Chlamydophila psittaci*<br>*Coxiella burnetii*<br>*Francisella tularensis*<br>Hendra virus<br>*Rickettsia prowazekii*<br>*Rickettsia typhi*<br>*Streptococcus suis*<br>Venezuelan equine EV | *Bacillus anthracis*<br>*Campylobacter jejuni*<br>Japanese EV<br>*Leptospira interrogans*<br>Puumala virus<br>*Salmonella typhimurium*<br>Tick-borne EV | *Brucella abortus*<br>Louping ill virus<br>*Toxoplasma gondii*<br>*Trypanosoma brucei rhodesiense*<br>West Nile virus | *Borrelia burgdorferi*<br>Sin Nombre virus<br>*Trypanosoma cruzi* | BSE<br>Rabies virus |
| III (Spillover + stuttering chains) | Andes virus<br>Lassa virus<br>Machupo virus<br>Nipah virus | *Leishmania chagasi*<br>Crimean-Congo HF virus<br>Monkeypox virus<br>*Yersinia enterocolitica* | *Leishmania infantum* | *E. coli* O157:H7 | Influenza A (avian)<br>*Mycobacterium bovis* |
| IV (Spillover + possible outbreaks) | Barmah forest virus<br>Dengue virus (sylvatic)<br>*Leishmania donovani*<br>Marburg virus<br>Mayaro virus | Chikungunya virus<br>Ebola virus<br>Ross River virus<br>Yellow fever virus | | *Yersinia pestis* | Influenza A (pandemic)<br>SARS-CoV |

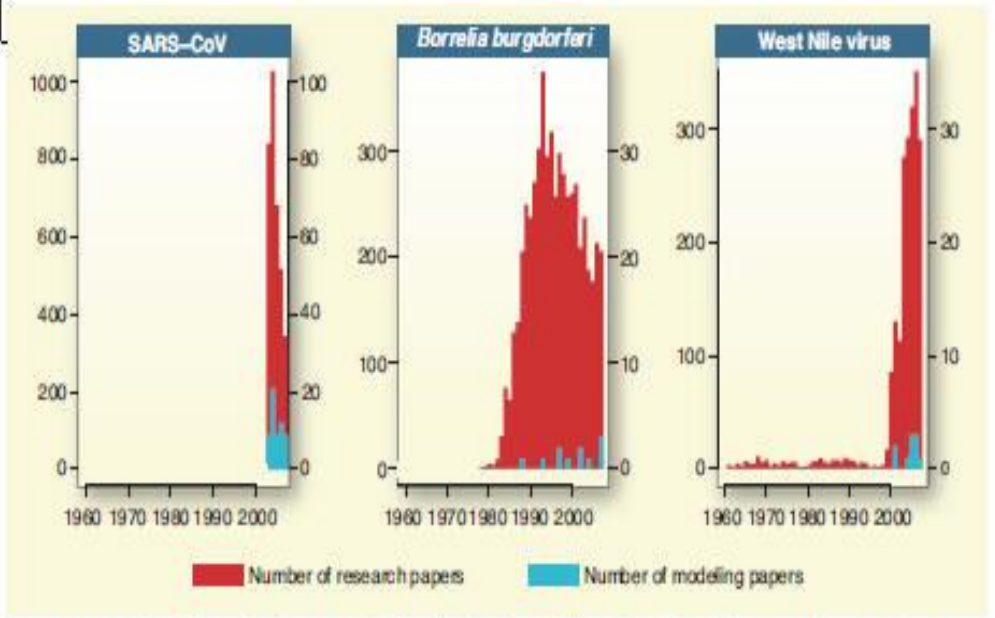



**Fig. 3.** Temporal profiles of total research effort (red) and modeling effort (blue) for recently emerged zoonoses. Figure panels have different *y*-axis scaling, but in each instance, the scaling for number of modeling studies (right axis) is 1/10th that for the total number of research papers (left axis).

Lloyd-Smith et al. *Science* (2009)

# Conclusions

- **Global climate change:** major implications for human health.
- Impacts on **ecosystems** will change distribution and burden of vector-borne infectious diseases, including bacterial diseases. **Changes in epidemiology may already be underway?**
- **Mitigation:** impact likely to be borne principally by already-vulnerable individuals and groups.

# Conclusions (2)

- **Surveillance**: Cornerstone of public health response.
  - Without measurement "flying blind".
  - Canada: Lyme nationally notifiable only in 2009.
  - Other diseases with potential climate links (echinococcosis, blastomycosis) not reportable in US or Canada.

# Acknowledgements


- **Collaborators:** Ashleigh R. Tuite (University of Toronto), Dr. Amy L. Greer (CRC, University of Guelph), Dr. Steve Drews (Alberta ProvLab and University of Calgary), Greg Kujbida (Peel Public Health), Dr. Laura Kinlin (Hospital for Sick Children), Dr. Vicky Ng (Public Health Ontario), Dr. Joe Tien (Ohio State University), Dr. Marissa Eisenberg (University of Michigan), Dr. Len Mermel (Brown University).
- **Funders:**
  - Canadian Institutes for Health Research
  - U.S. National Science Foundation
  - Novartis Vaccines