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Challenges in Addressing Weather-and-Climate Sensitive Health Impacts

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NSF

Weather/Climate & Health Program at NCAR

- **Strategy: An integrated approach to assessing and addressing health risks that encompasses both the physical environment and socio-economic drivers. Our long-term goal is to generate quantitative models of weather-and-climate-related health risks.**

Extreme heat (NASA IDS)

***Aedes aegypti* (NSF – CNH/EEID)**

Plague (CDC/USAID)

Meningitis (Google.org - NSF CNH)

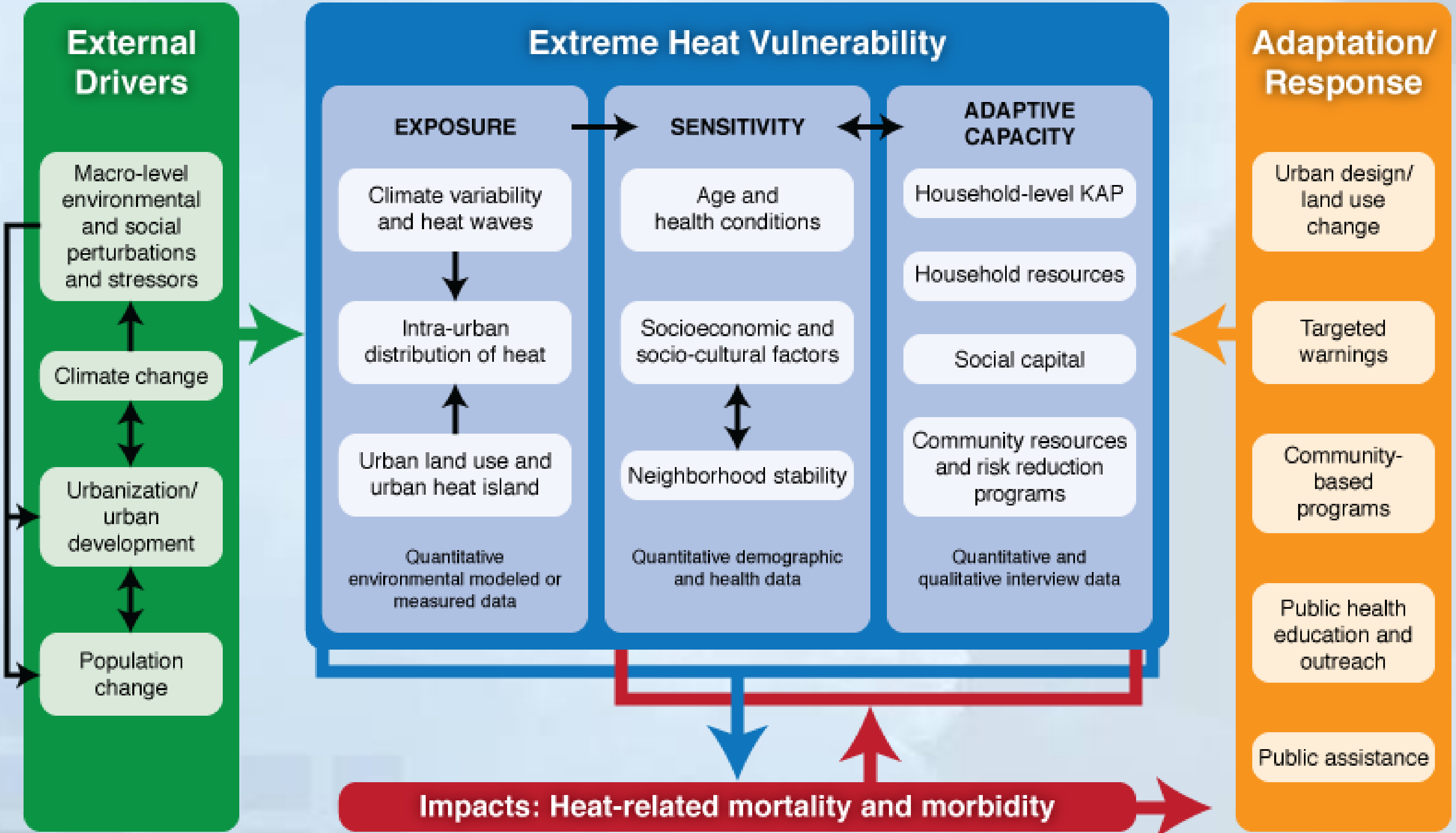
Outline

1. Framework for integrated physical and social sciences work at NCAR

2. Examples of current research at NCAR

3. Challenges for modeling health impacts

Research framework



Wilhelmi and Hayden (2010, ERL)

System for Integrated Modeling of Metropolitan Extreme Heat Risk (SIMMER)

NCAR

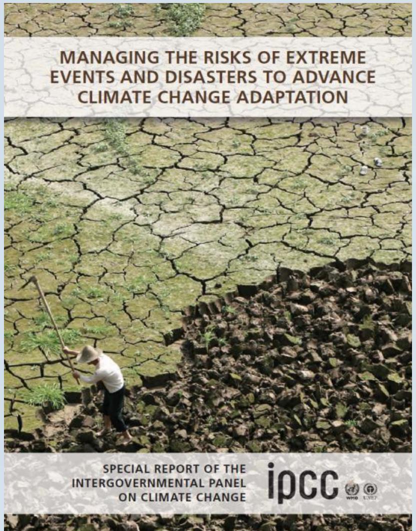
RAL

CGD

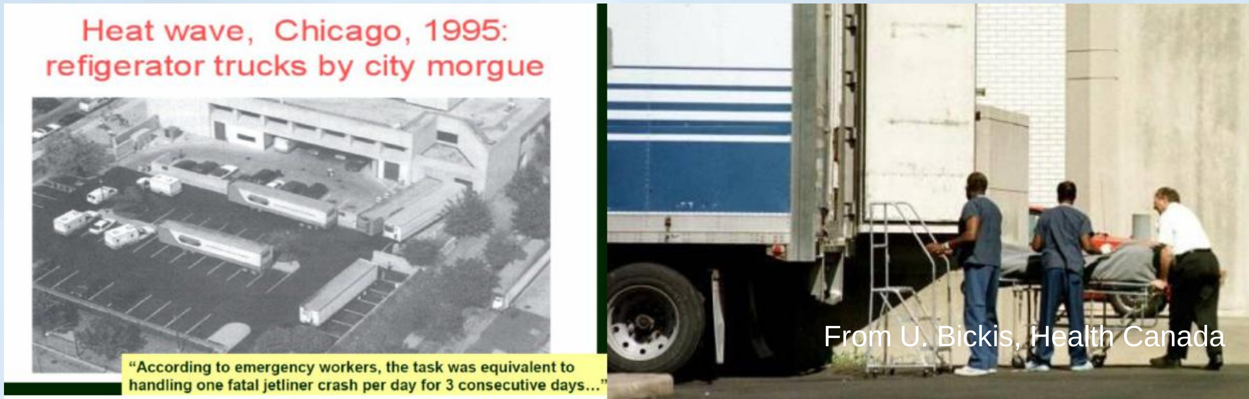
IMAGe

Motivation

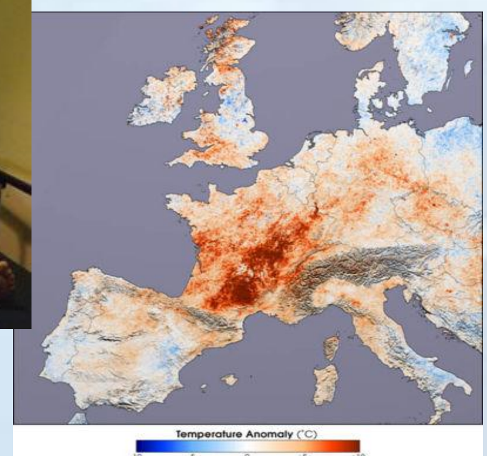
- Extreme heat and climate change are public health concerns
  - Observed impacts – hottest July on record
  - Projected changes in extreme heat events (IPCC 2012)
- Cities
  - Urban heat island effect
- Impacts (adverse health outcomes) are distributed unevenly
  - Societal vulnerability
- Relationship between human health and extreme heat is a complex medical, social and environmental issue
  - Information is needed for public health interventions and climate adaptation

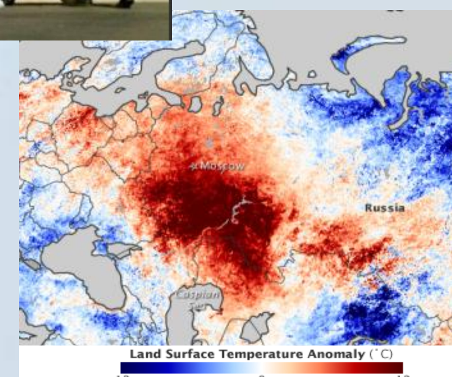


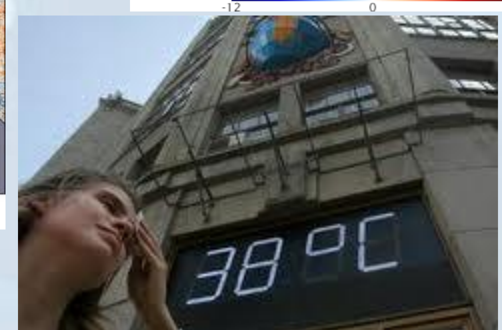
Extreme Heat *Events*



Patients being treated during the French heat wave of 2003. Photo: Martin Bureau/AFP



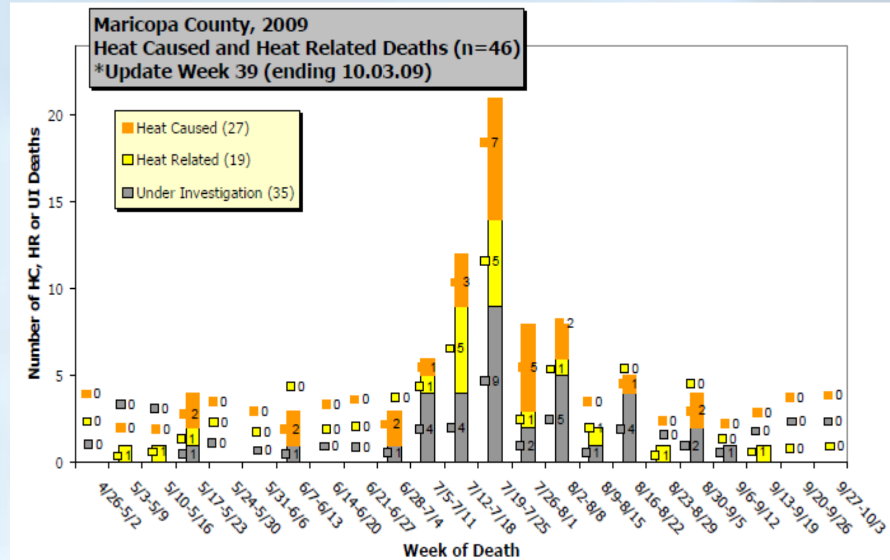


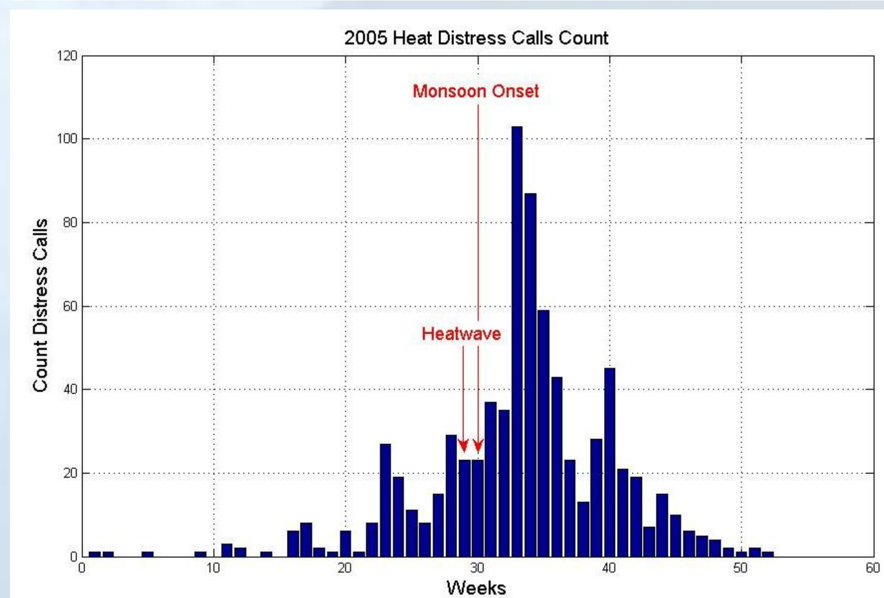


Russian heat wave" of 2010 (photo: Moscow Times)

Extreme Heat *in Hot Climates*

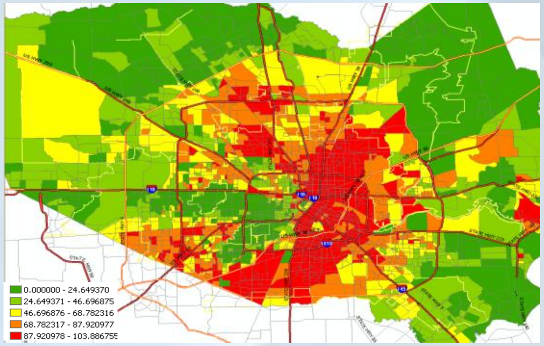
People waiting for the bus in Phoenix, AZ. Photo: O. Wilhelmi

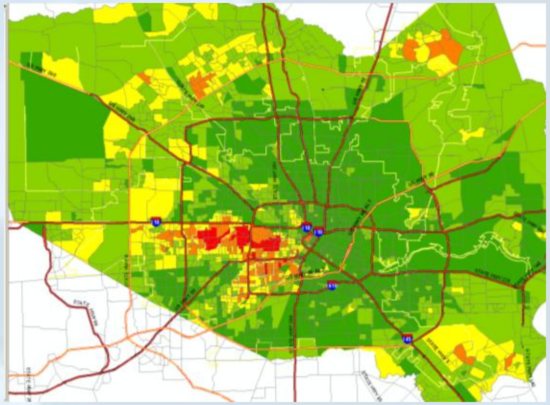


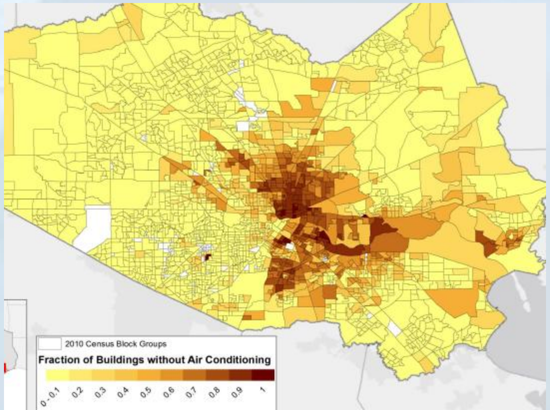


Characterizing societal vulnerability and responses

- **Spatial representation of sensitivity and adaptive capacity**
  - age, income, social isolation, education, pre-existing health conditions, location, household resources, access to cooling
- **Data sources:**
  - US Census (block groups)
  - American Community Survey
  - Parcel /building database
  - Household survey

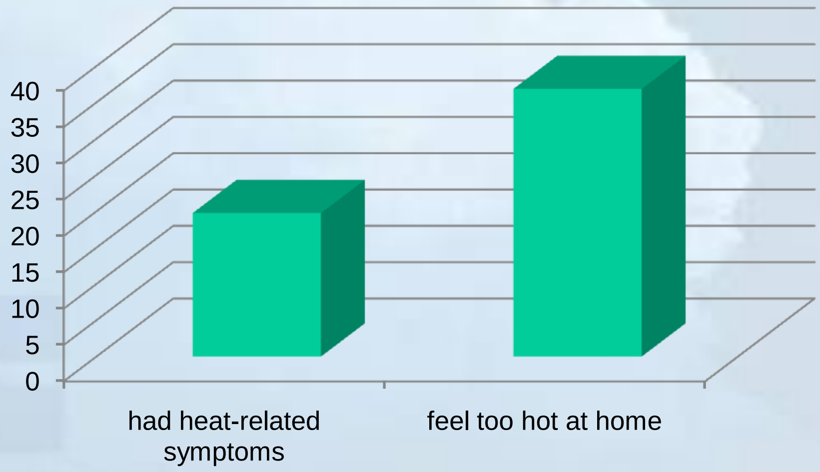




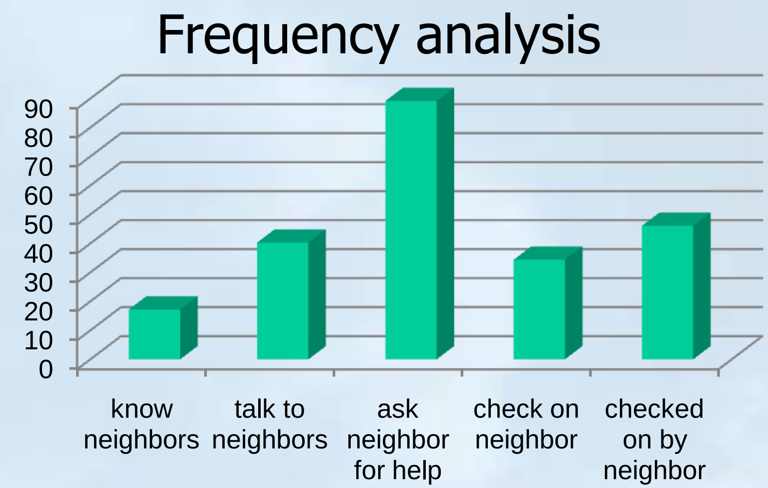


Adaptive capacity

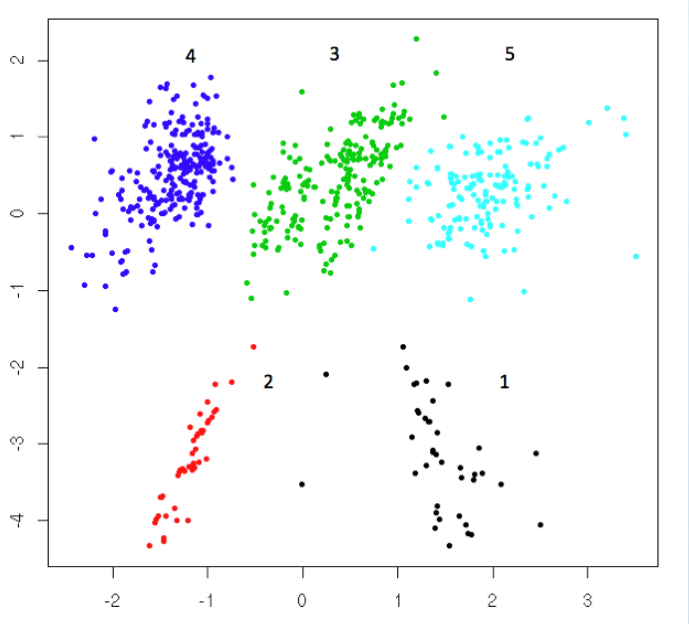
- Critical component in climate adaptation
- Social and behavioral factors of vulnerability
- Houston: 2011 household survey (n=901); 2012 stakeholder survey and 2012 8-9 focus groups (ongoing)
- ~ 60 questions about Knowledge, Attitude, Practices (KAP), Social capital, Household Resources and Community/Government Programs

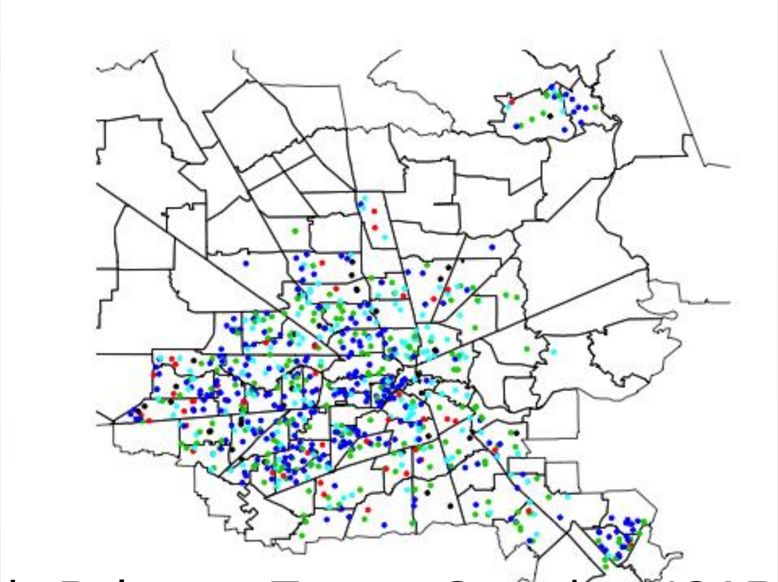


Social capital (an example)



Multidimensional Scaling





Jamie Pelzman, Tammy Greasby, NCAR

Climate adaptation and extremes

- Developing climate change adaptation strategies requires
  - Better understanding of impact of climate change and weather extremes
  - Better understanding and characterization of societal vulnerability
  - Context-specific extreme heat mitigation and response actions
- Engagement of stakeholders from both the top-down and the bottom-up allows the opportunity to better characterize health risks and develop sustainable policies for public health climate adaptation

Vector-borne Diseases

What are vector-borne diseases?

- Vector-borne diseases are caused by micro-organisms (e.g., viruses, bacteria, protozoa) that are transmitted by arthropod vectors (e.g., fleas, ticks, mosquitoes).

- Vector-borne diseases cause significant morbidity and mortality globally, but especially in the tropics and subtropics (e.g., malaria, plague, Rift Valley fever, dengue).

Annual Vector-borne Disease Burden, Global

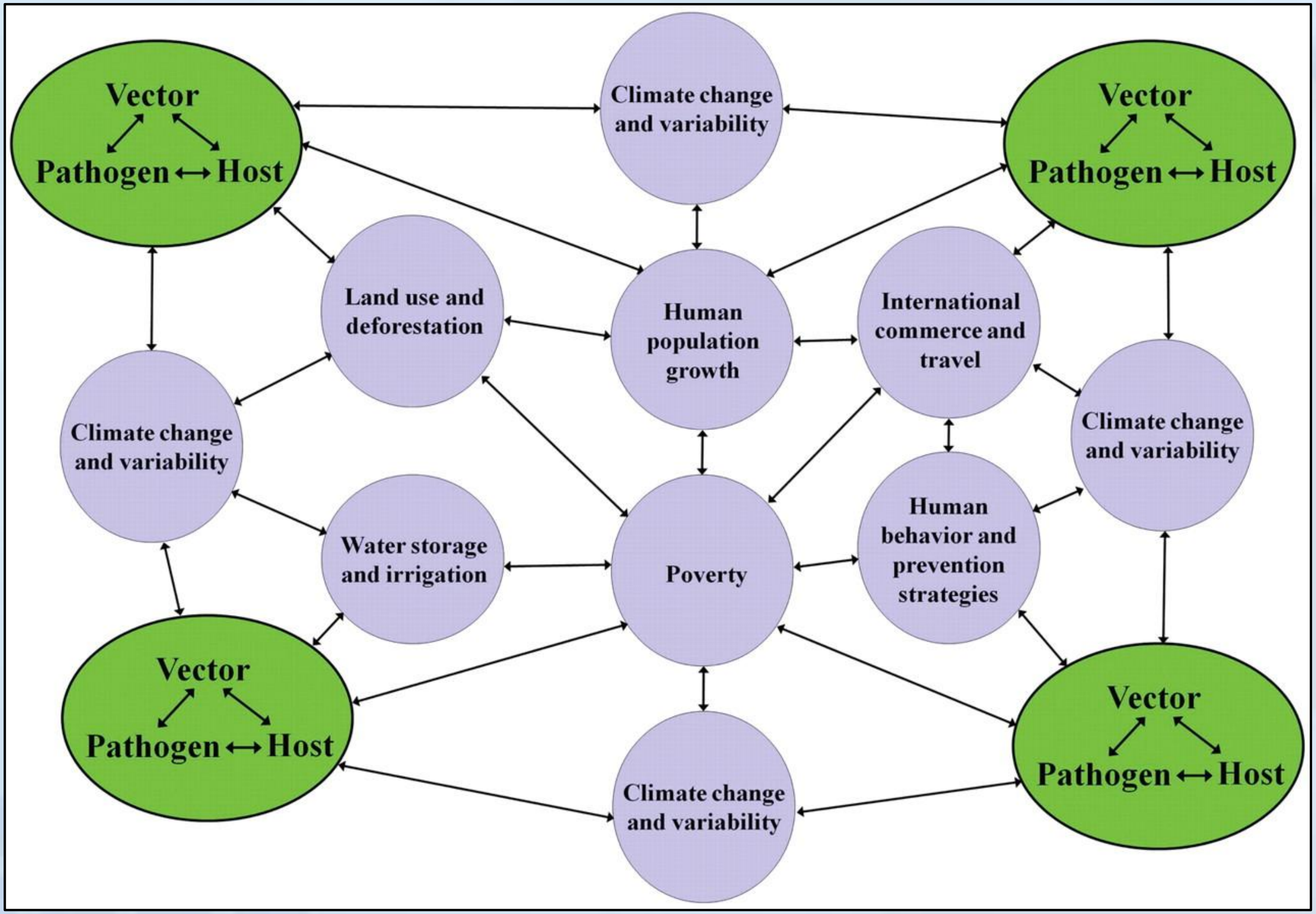
Disease	Disease Burden (DALYs[a]) in Thousands	Mortality in Thousands
Malaria	42,280	1,124
African trypanosomiasis	1,598	50
Lymphatic filariasis	5,644	0
Dengue fever	653	21
Leishmaniasis	2,357	59
Chagas disease	649	13
Onchocerciasis	987	0

[a]DALYs – Disability Adjusted Life Years (the number of healthy years of life lost due to premature death and disability).

VBDs annually cause about 50 M lost life years, 1.5 M deaths

Kalluri et al. 2007

Vector-borne Disease Systems



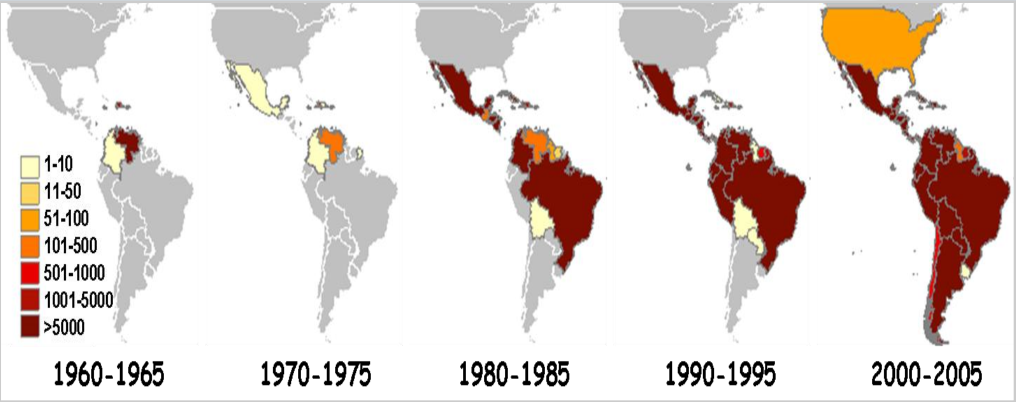
VBDs are extremely complex!

Tabachnick 2010

Aedes aegypti along an elevation gradient in Mexico

Dengue Fever

- Dengue Fever and Dengue Hemorrhagic Fever are caused by dengue viruses transmitted by *Aedes* mosquitoes
- Annually, 100 million people contract dengue worldwide
  - 500,000 people develop severe dengue hemorrhagic fever every year
  - No approved vaccine available
  - Increasing number and severity of cases in the Americas…



Source: WHO DengueNet

Estimated Distribution of Dengue in Mexico, Present Day

Regions of ongoing dengue transmission in Mexico and surrounding countries (shaded). Red markers indicate reports of local and regional dengue transmission during the first 3 months of 2011. (Source: DengueMap – a CDC-HealthMap collaboration)

Aedes aegypti and Temperature

Immature Development

- Thermally constrained (as well as by water/organic load); the higher the temperature, the quicker the immatures develop into adults

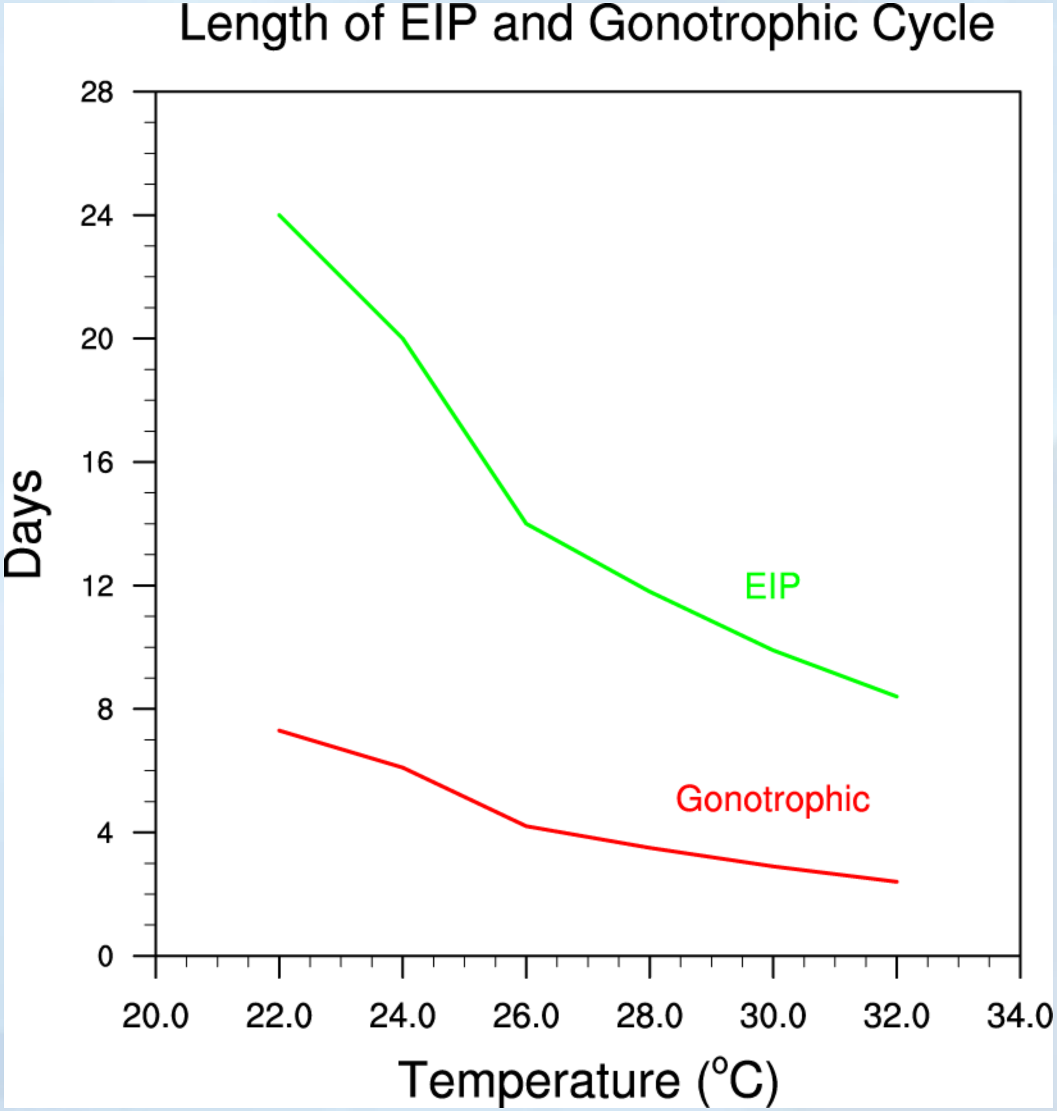
Extrinsic Incubation Period

- Time needed for a newly infected female mosquito to become infectious
- Temperature dependent
- However, probability of transmitting virus also varies with how often the female bites – a function of length of gonotrophic cycle

Gonotrophic Cycle

- Time between ingesting a blood meal and oviposition; temperature dependent

Length of EIP and Gonotrophic Cycle vs. Temperature

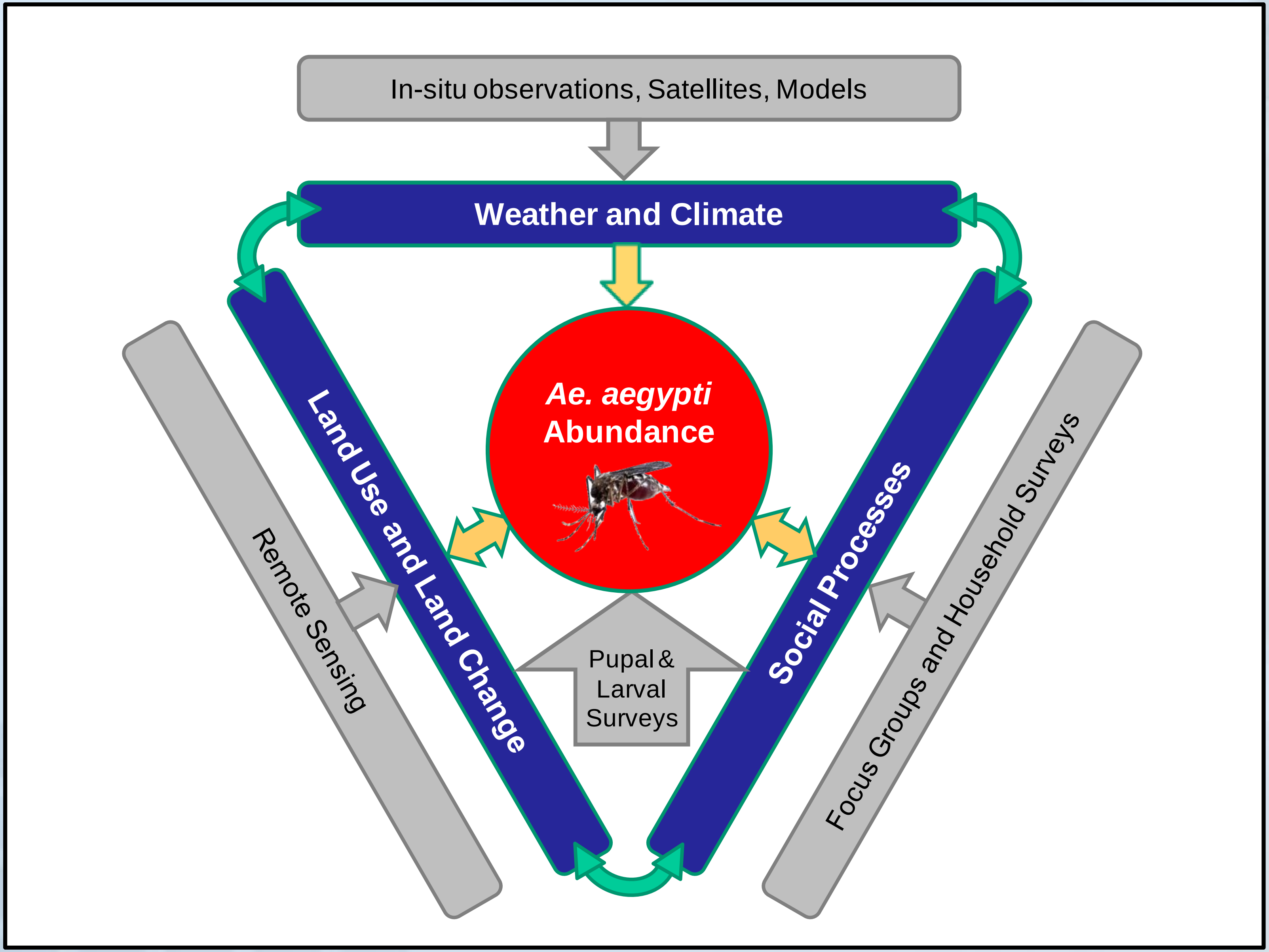


Adapted from Focks and Barrera 2006

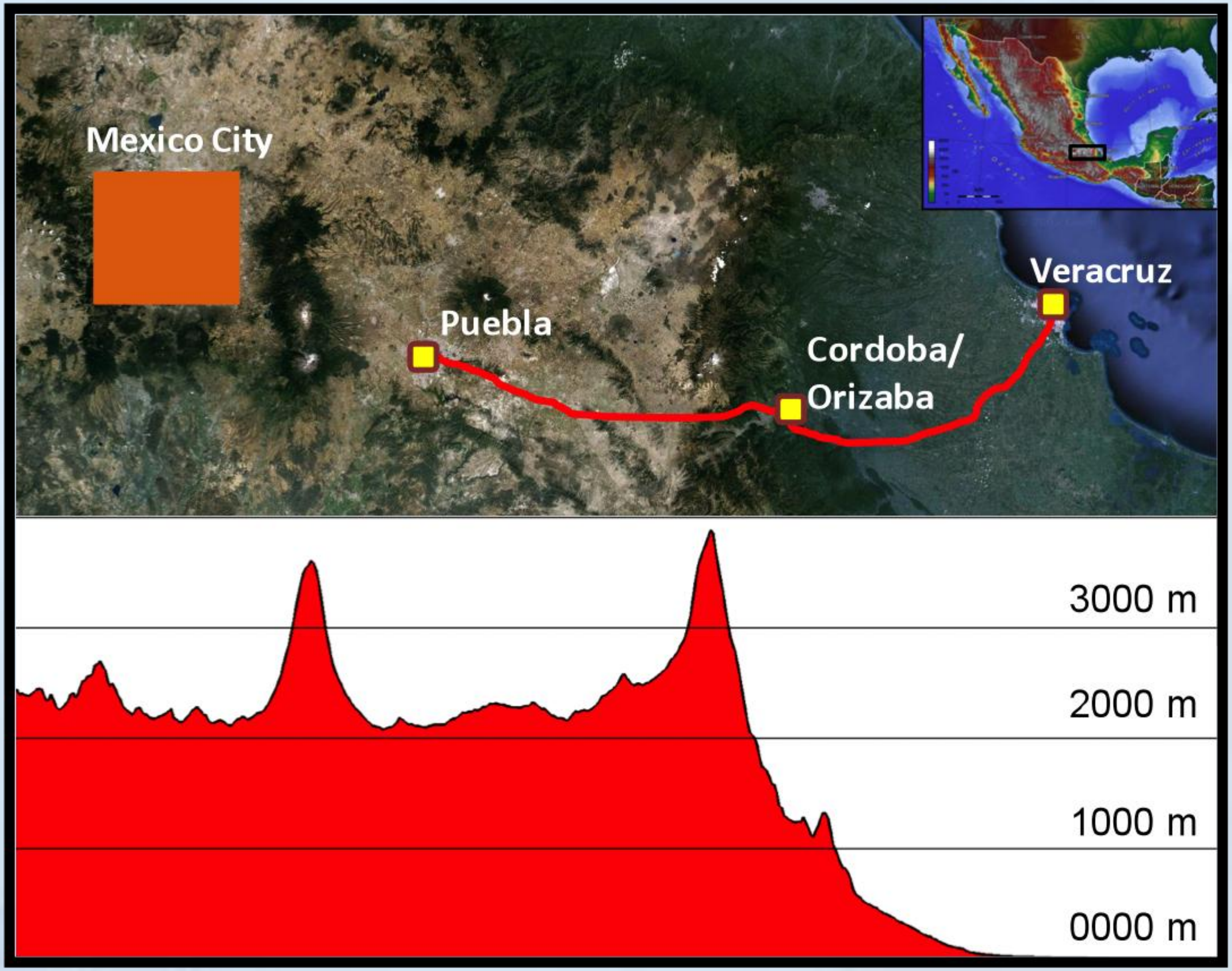
Aedes aegypti and Precipitation

- Oviposits in artificial containers
- Containers can be rain-filled (tires; discarded items) or filled manually (potted plant bases; buckets; 55 gallon drums)
- Manually filled containers provide oviposition sites even in times of drought
- Even with ‘reliable’ piped water, people store water

Framework for *Aedes aegypti* Study



Main Transect in Study Region



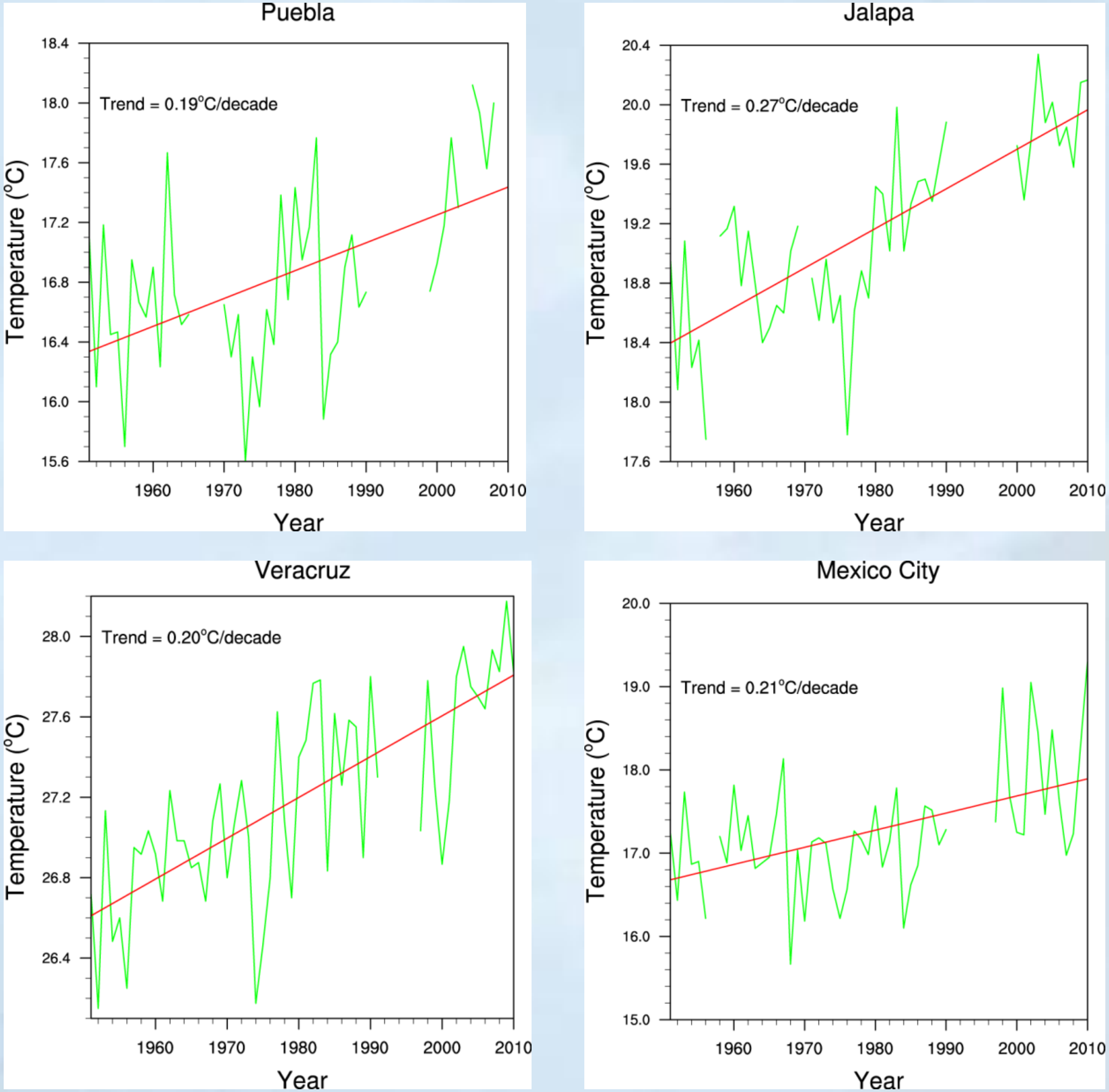
Research Activities – Summer 2011, 2012

- Collect weather and climate data (*in situ* observations; satellites)

- Collect data on mosquito presence/abundance (larval and pupal surveys; oviposition traps along gradient – 2011
- Collect pupae and adults in areas at the margins of transmission - 2012

- Conduct focus groups and household surveys

Temperature Trends from 1951 - 2000

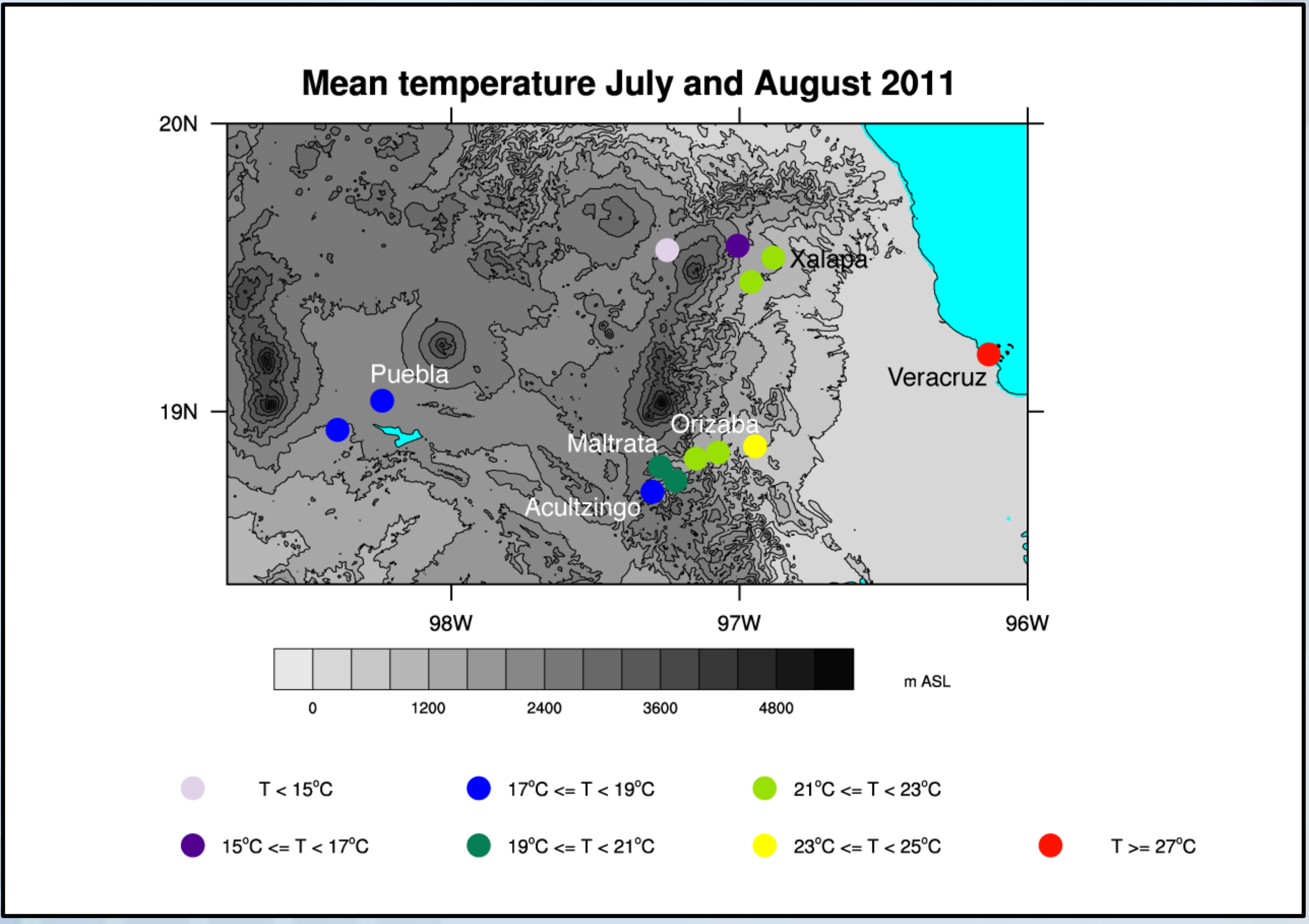


Wet season (May-October) temperature (°C) trend over 1951-2010 period.
Source: NASA GISS

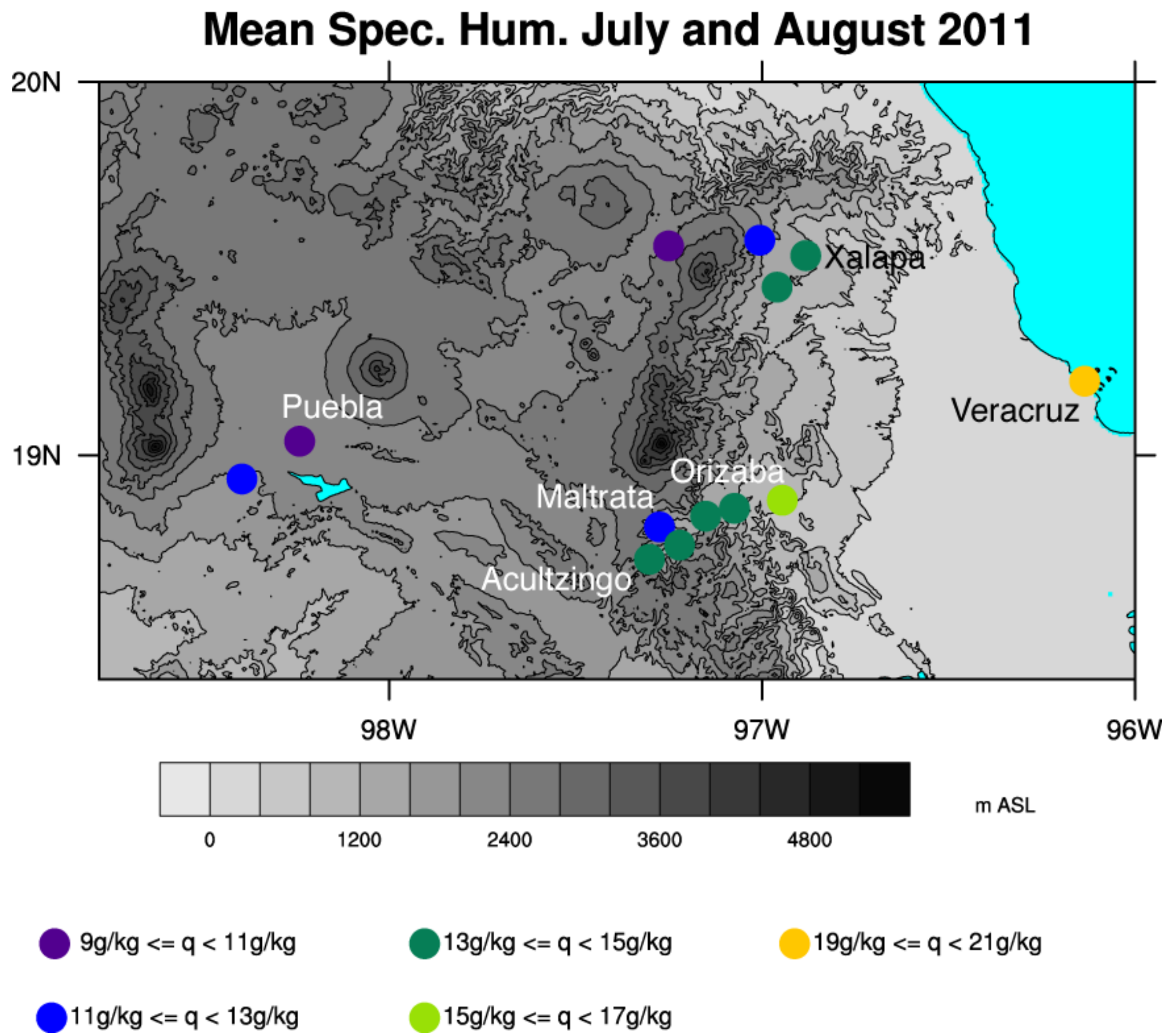
Climate Data Collection

- Install 1-2 HOBO™ temperature/humidity sensors in each community.
- Collect satellite-based rainfall data (CMORPH, TRMM)
- Supplement data with long-term records from available Mexican weather stations

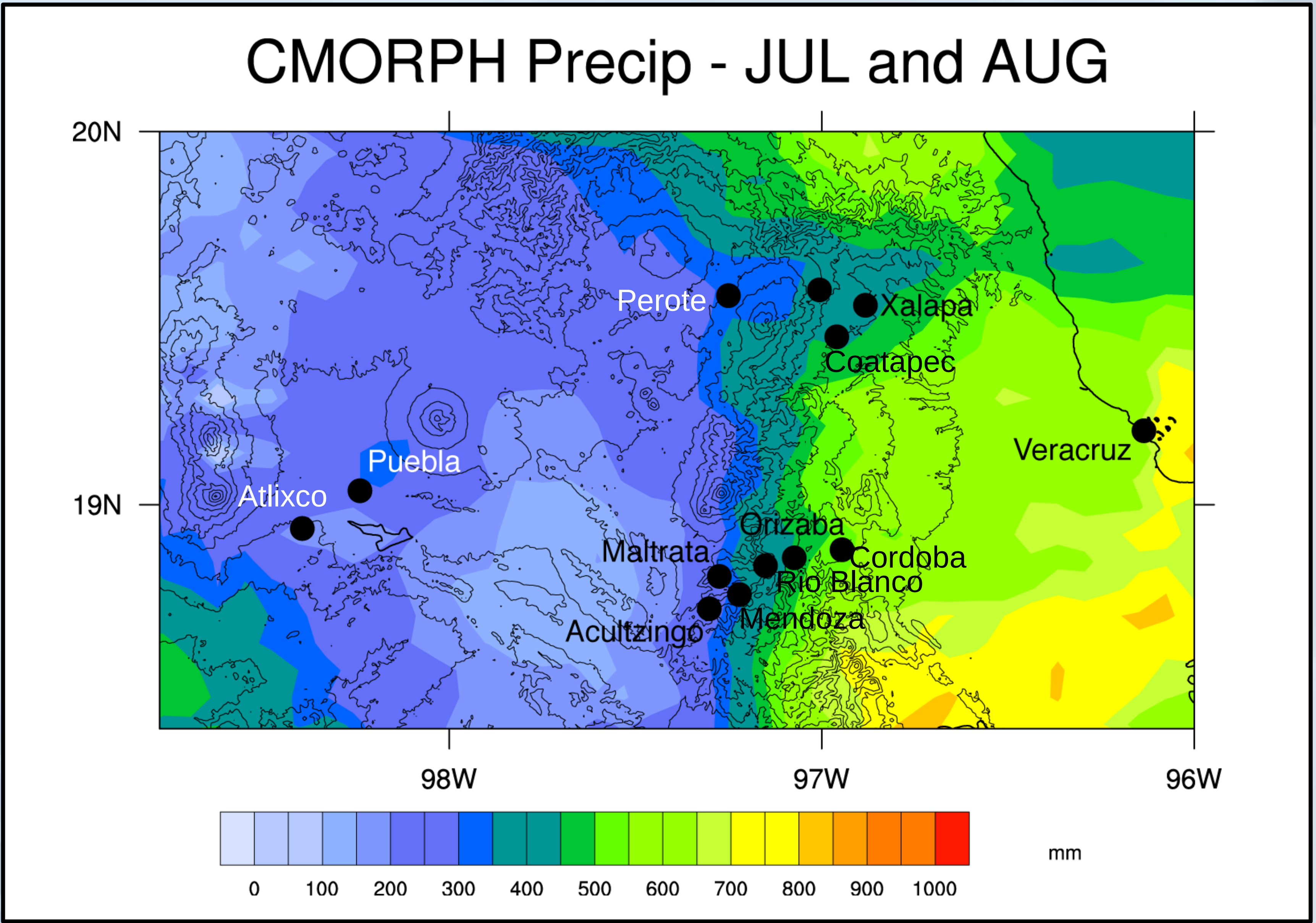
Climate along Transect: Temperature



Climate along Transect: Specific Humidity



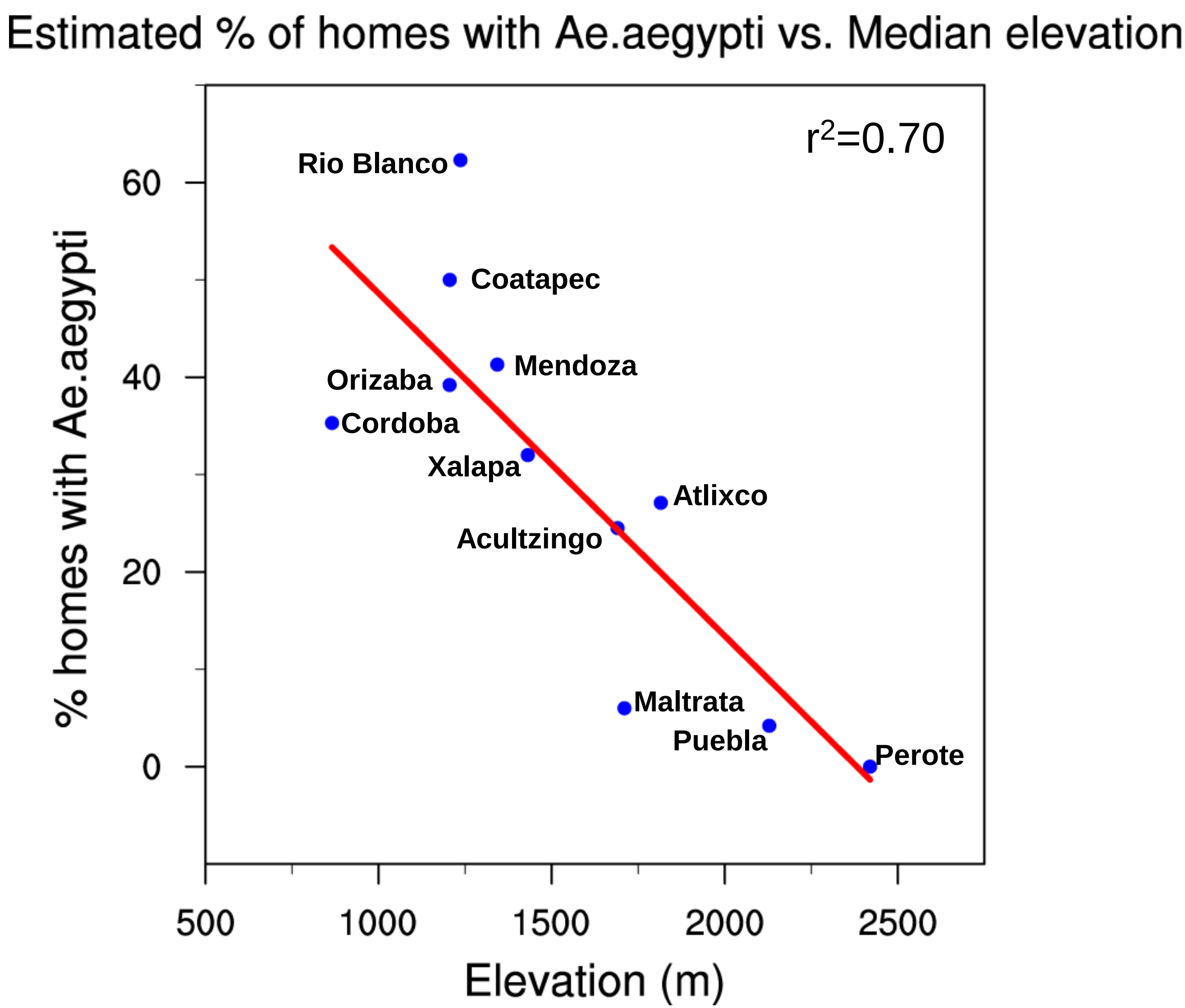
Climate along Transect: Rainfall



Mosquito Sampling Strategy 2011, 2012

- Collect immature mosquitoes and eggs in cities located along an elevation/climate transect in 2011 from a low elevation at Veracruz (0-40m) to high elevation at Puebla (2150 m).
- Immature samples collected at 50 or more locations (households/cemeteries) in each of 12 communities during July – September 2011. Total of ~600 households.
- Multiple collection periods of pupae and adults in 4 cities at higher elevations (margins of transmission) in 2012. Total of ~600 households.
- Mosquitoes reared locally and shipped to CSU for identification in 2011 and 2012.

Results from 2011

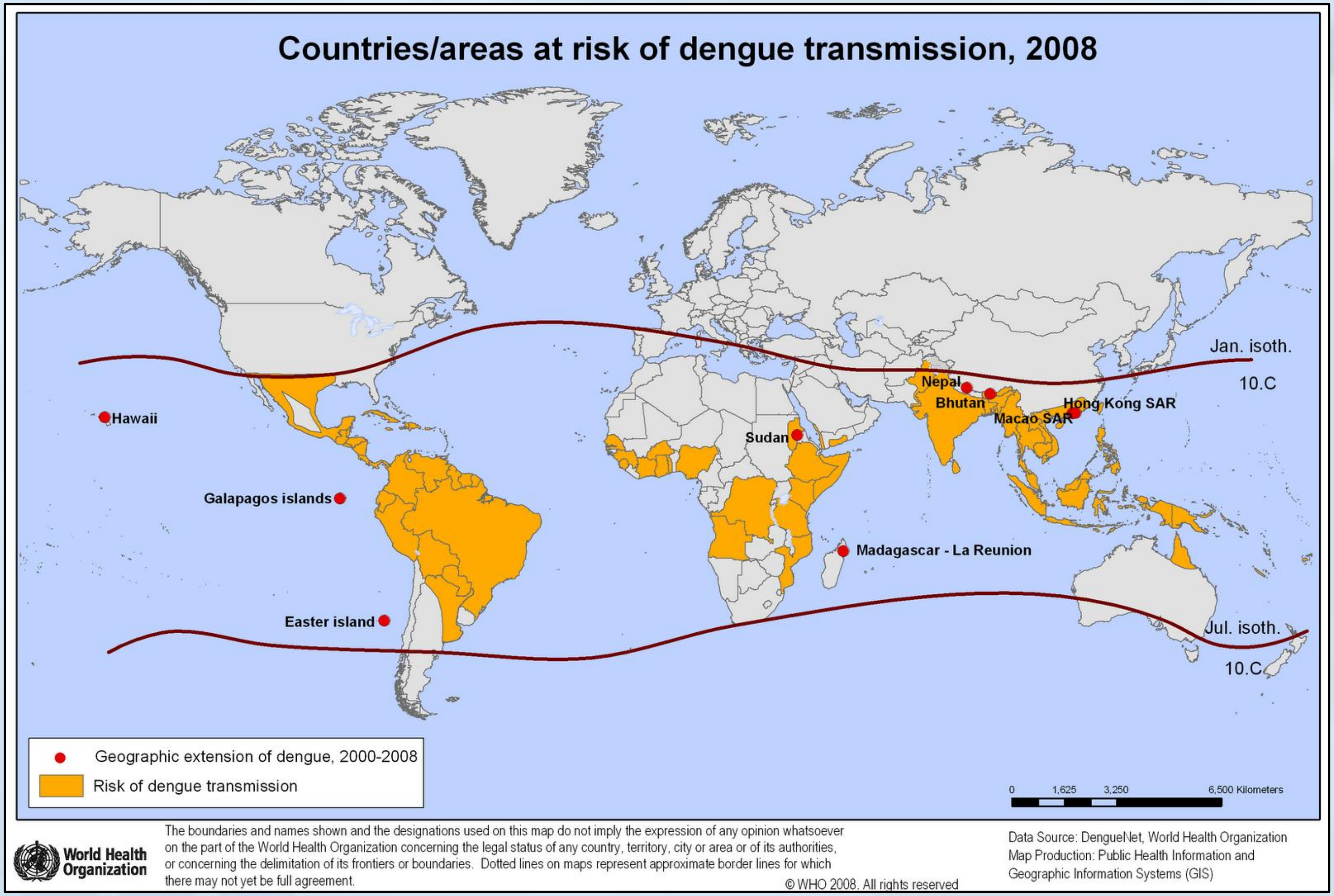


**Based on sample of ~50 homes per community*

Focus Groups – Summer 2011 Household Surveys – 2011, 2012

- Sixteen FGs conducted in 4 communities along the transect
- Household surveys in 600 households each year
- Information for from FGDs used in development of household survey
  - Water storage practices
  - Human-mosquito interactions/barriers such as screens
  - Cultural practices
  - Perception of dengue risk in community

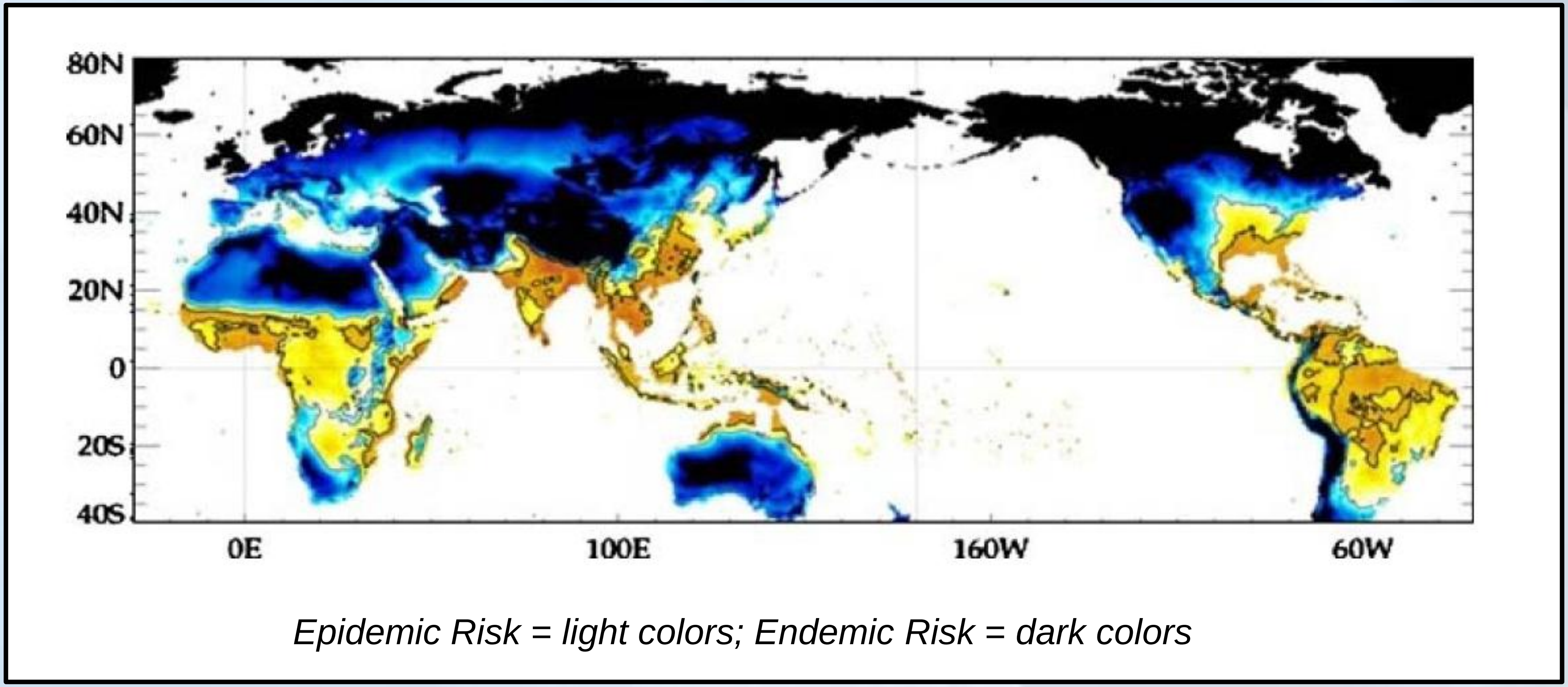
Dengue Risk based on case surveillance



Cases are confined within seasonal minimum temperature threshold

World Health Organization, 2008

Modeled Dengue Risk, 1970-2000 average



Model suggests epidemic risk occurs outside 'traditional' bounds.
Is it true? What factors might have been neglected?

Degallier et al. 2010

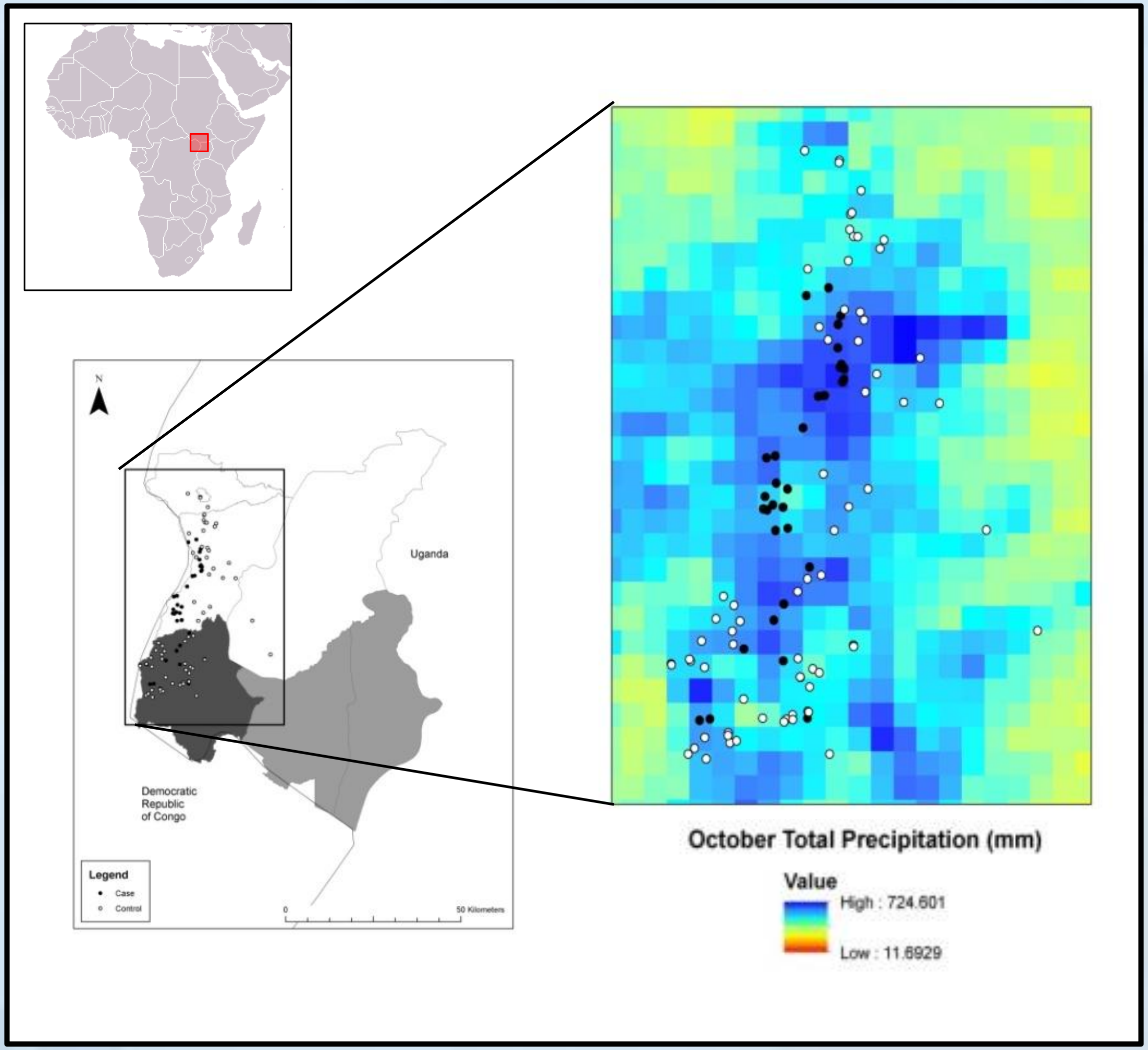
Plague in Northwest Uganda

Plague in Northwest Uganda

West Nile region

- **Plague is a highly virulent and flea-borne disease caused by *Yersinia pestis*.**
- **Infected fleas travel on rats that intermittently come into contact with humans**
- **Local rat and flea populations fluctuate in response to weather and climate variability**

Observed Plague Cases in Uganda



Cases are associated with wetter, cooler regions

Monaghan et al. 2012; MacMillan et al., 2012

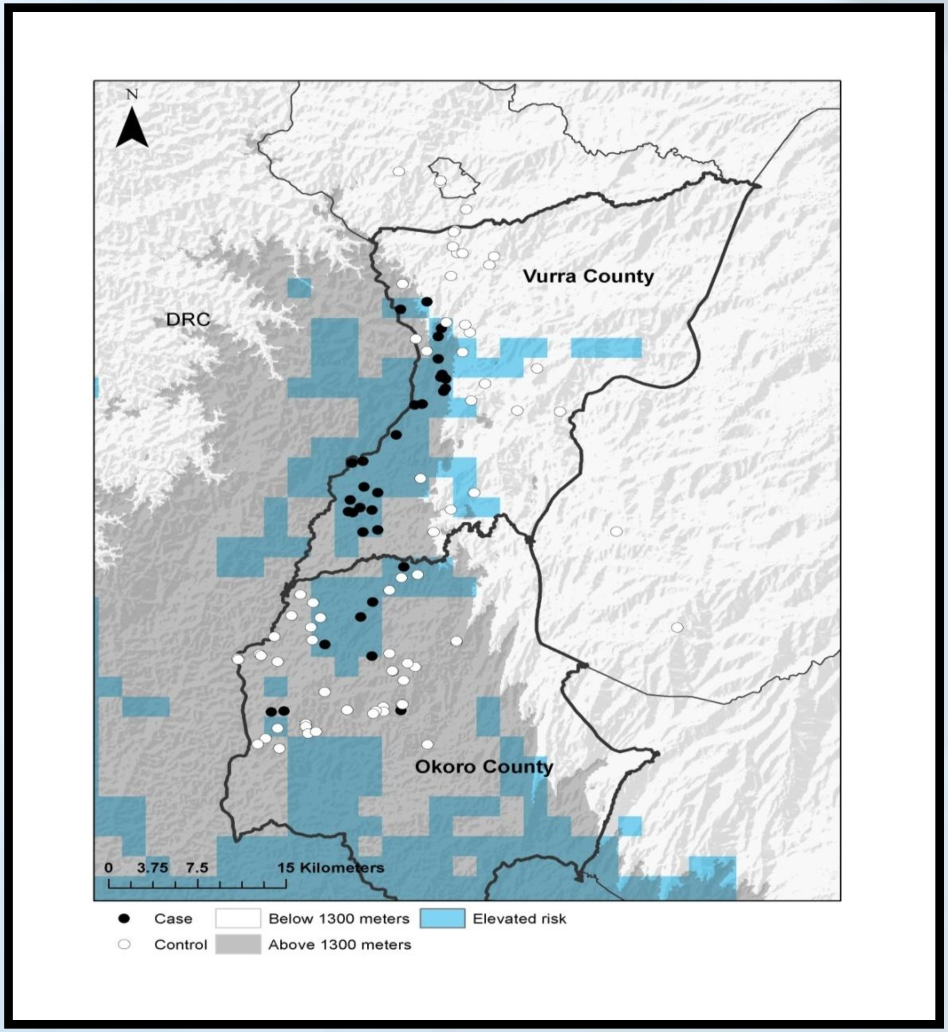
Modeled Spatial Plague Risk, Uganda

Case and control locations were discriminated based on the following climatic variables (10 yr averages).

- Total precipitation at tails of rainy season (+)
- Total precipitation during annual dry spell (-)
- Above 1300 m (+)

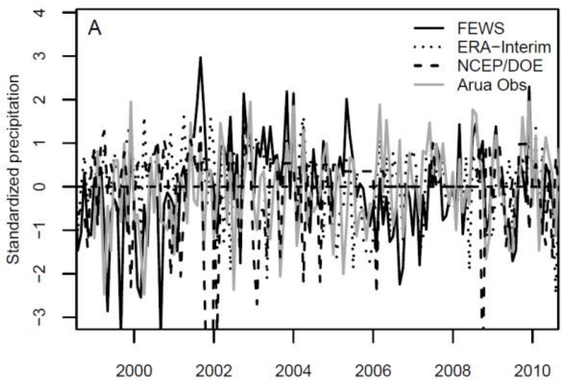
Model Accuracy = 94%

Is model valid outside of focus region?

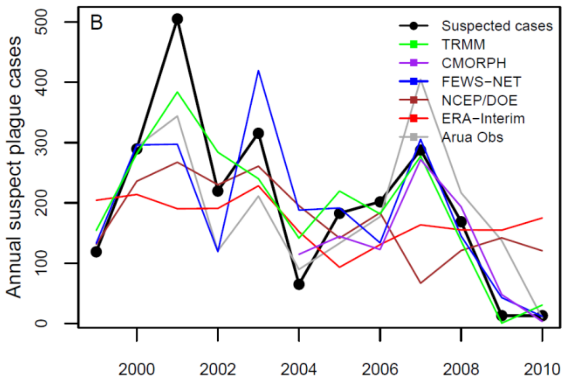


Monaghan et al. 2012; MacMillan et al., 2012

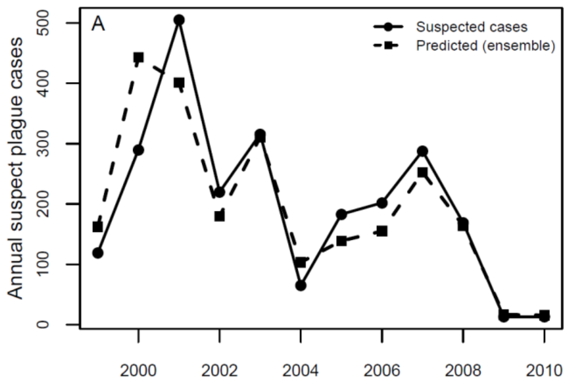
Modeled Temporal Plague Risk, Uganda



Monthly Rainfall



Modeled Annual Risk
(per rainfall dataset)



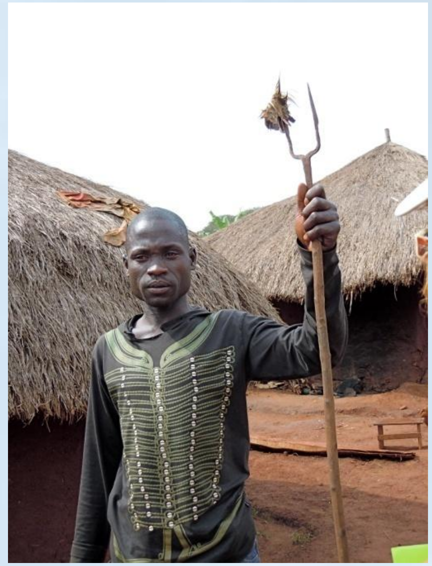
Modeled Annual Risk
(ensemble)

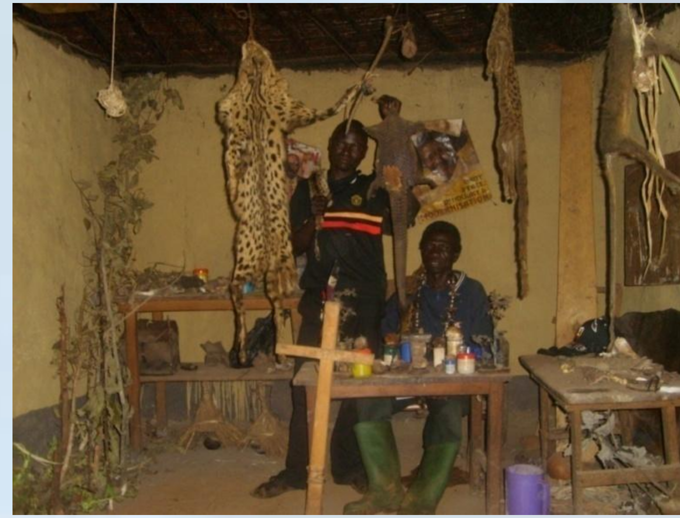
Meteorological data are highly uncertain in many regions of greatest risk.

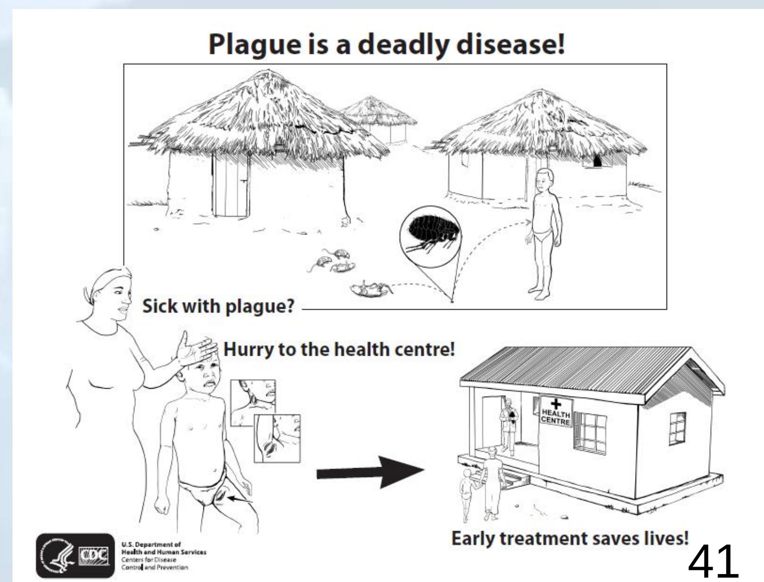
Ensemble modeling techniques may help.

Moore et al.PLoS One (in press)

Training Traditional Healers







Motivation

- **Why interest in traditional medicine and plague?**
- **Public health concerns**
  - Delays in care seeking, may contribute to mortality
  - Gap in surveillance—may be underestimating, misunderstanding aspects of the disease
  - Occupational risk for healers
- **Potential public health benefits**
  - Improved patient outcomes
  - Facilitate collaboration, improve referral and patient outcomes (beyond plague, too)
  - Improve understanding of plague epidemiology

Expanding Surveillance

- **DVBD and Uganda Virus Research Institute launched a project in July 2009 to:**
  - Understand traditional healers' knowledge of and experience with plague in Arua and Nebbi districts
  - Assess feasibility of increasing traditional healer referral of potential plague cases

Challenges

- **Lack of plague cases good for Ugandans, challenge for evaluation of surveillance**
- **Sustainability**
  - Healers need contact with program or clinic staff
  - Airtime needs to be re-filled
  - Bicycles need to be repaired
- **Recording referrals at clinic level demands resources**
- **What devotion of resources is appropriate?**
  - What is appropriate to ask without providing logistic resources?

Next Steps

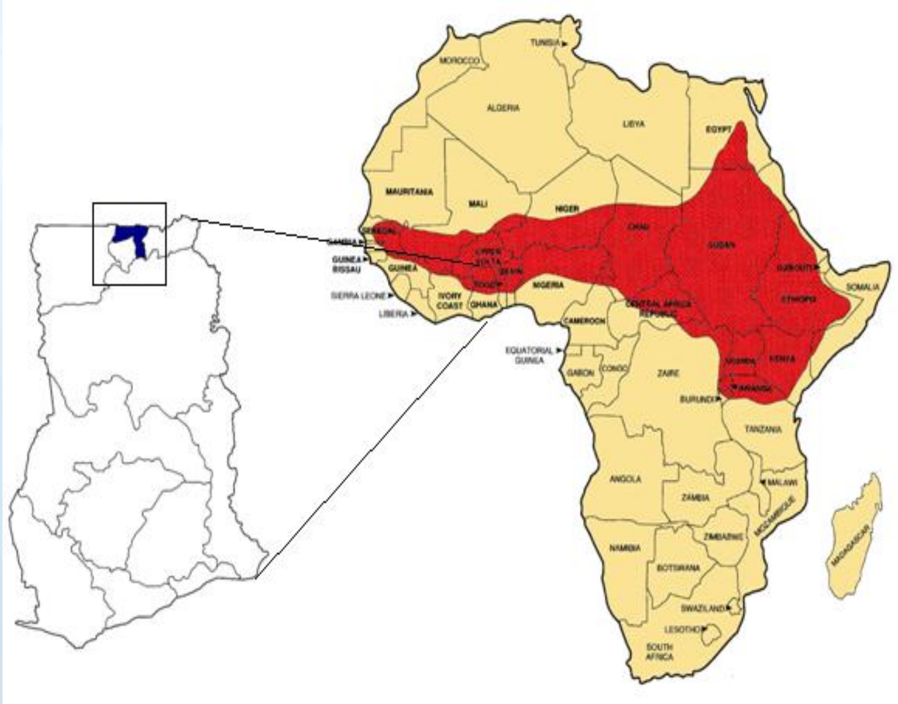
- **Survey to understand care seeking behavior at the household level**
  - Who is seeking healers and why?
- **Include healers in effort to have early reports of “ratfall” and collection of dead rats**
  - Expanding ecological surveillance
- **Evaluate expansion of healers’ referral network in ~1 year**

Meningitis in Ghana

Managing Meningitis in the Sahel

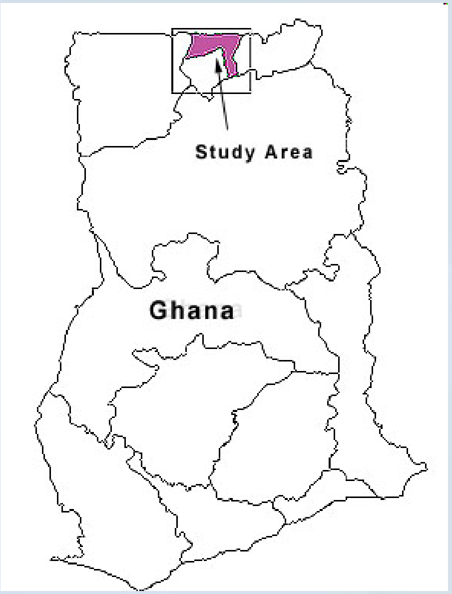
Motivation:

- Meningitis is endemic in the Sahel in countries with a distinct wet-dry season
- Infectious disease due to bacterium – *Neisseria meningitidis*
- Epidemic in 1996-1997 resulted in 250,000 cases and 25,000 fatalities
- Person-to-person transmission through respiratory and throat secretions –
- A reactive vaccine strategy is currently used to manage epidemics in Ghana
  - *Doesn't prevent transmission of the disease by the individual vaccinated*
  - *Only lasts one-to-two years*
  - *Doesn't produce an immune response in children under two*



Knowledge, Attitudes and Practices Survey

- Study in KN District in northern Ghana (pop. 150,000)
- Survey conducted between May 2010 and May 2011
- Structured questionnaire focused on knowledge of meningitis, health care seeking behaviors, and cost of illness
- Case control study with a total of 222 participants –
  - 74 laboratory confirmed cases
  - 148 controls matched by age, gender and geographic location
  - 48% male, 52% female



Socio-demographics of Participants

AGE	Control	Case	Total (n=222)
< 18 years	85	42	127 (57%)
> 18 years	63	32	95 (43%)

EDUCATION	Control	Case	Total
No education	90	45	135 (61%)
Primary/JHS	46	20	66 (30%)
SHS	5	5	10 (4%)
Tertiary	7	4	11 (5%)

OCCUPATION	Control	Case	Total
Unemployed	6	4	10 (11%)
Farmer	27	8	35 (37%)
Self-employed	19	9	28 (30%)
Student	7	6	13 (14%)
Gov’t employee	3	4	7 (8%)

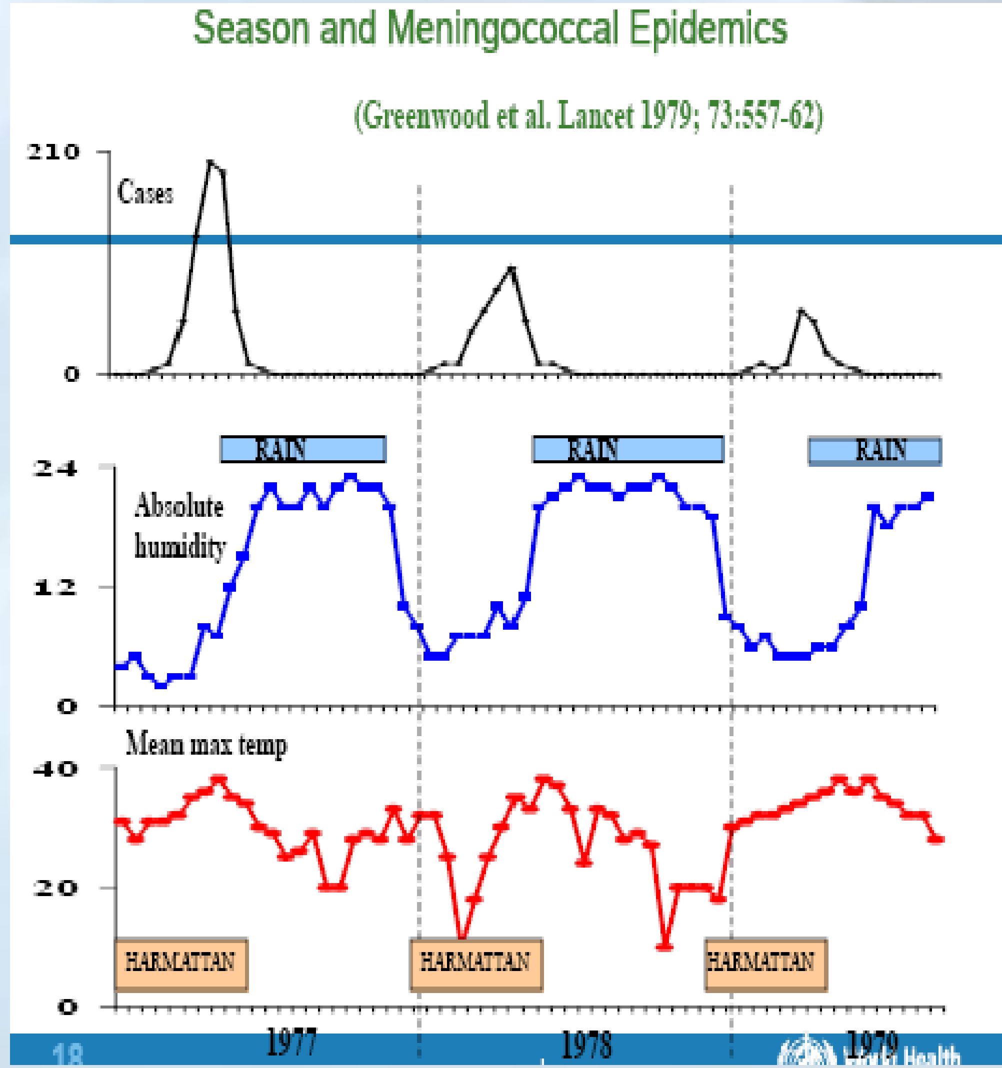
Signs and Symptoms of Meningitis

Signs/Symptoms	Odds Ratio	p-Value
High body temperature	0.44	0.015
Stiff neck	0.91	0.764
Vomiting	0.34	0.006*
Severe headache	0.52	0.038
Stiffness of waist	0.19	0.000*
Loss of appetite	0.19	0.000*

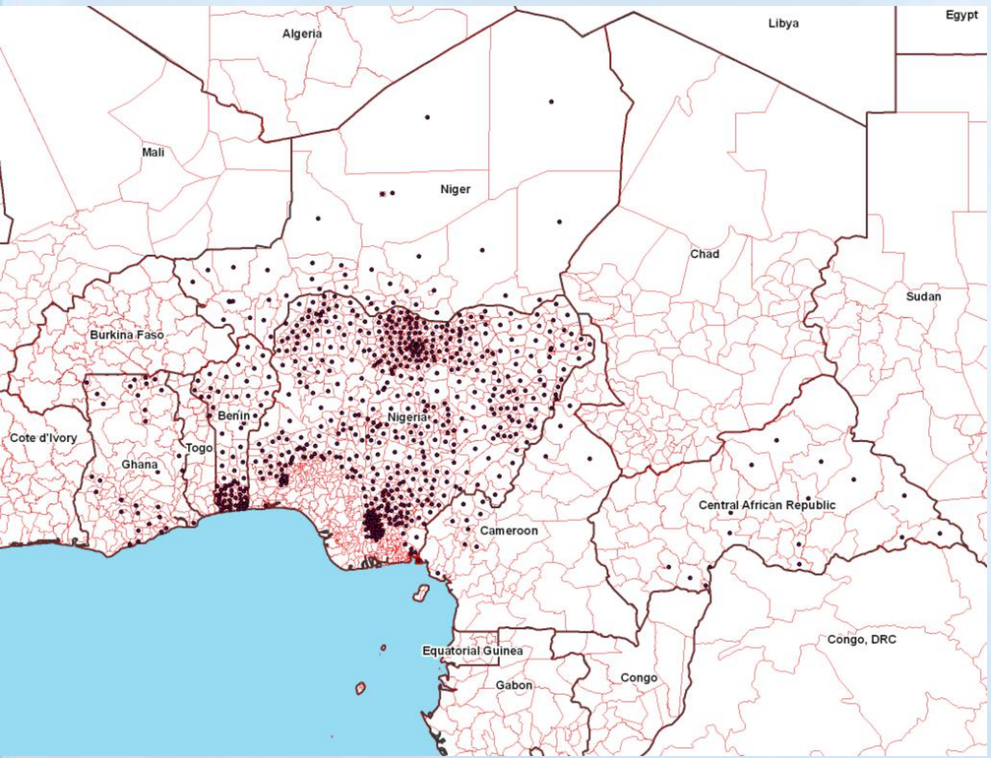
*Highly significant differences between cases and controls

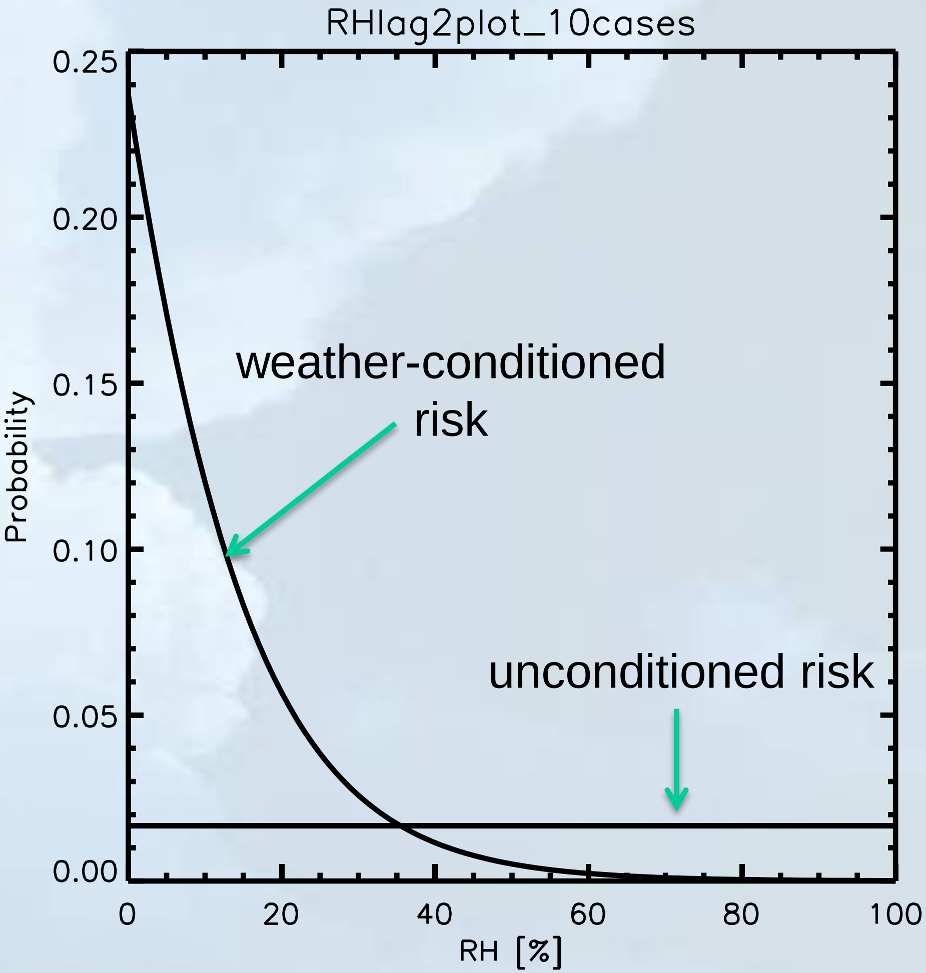
Weather Affects Meningitis Transmission

- *Nm. meningitidis* epidemics are observed to occur in the dust season and end with the onset of the rainy season
  - Can humidity forecasts help identify regions where the epidemic will end naturally, so that scarce vaccines can be moved elsewhere?



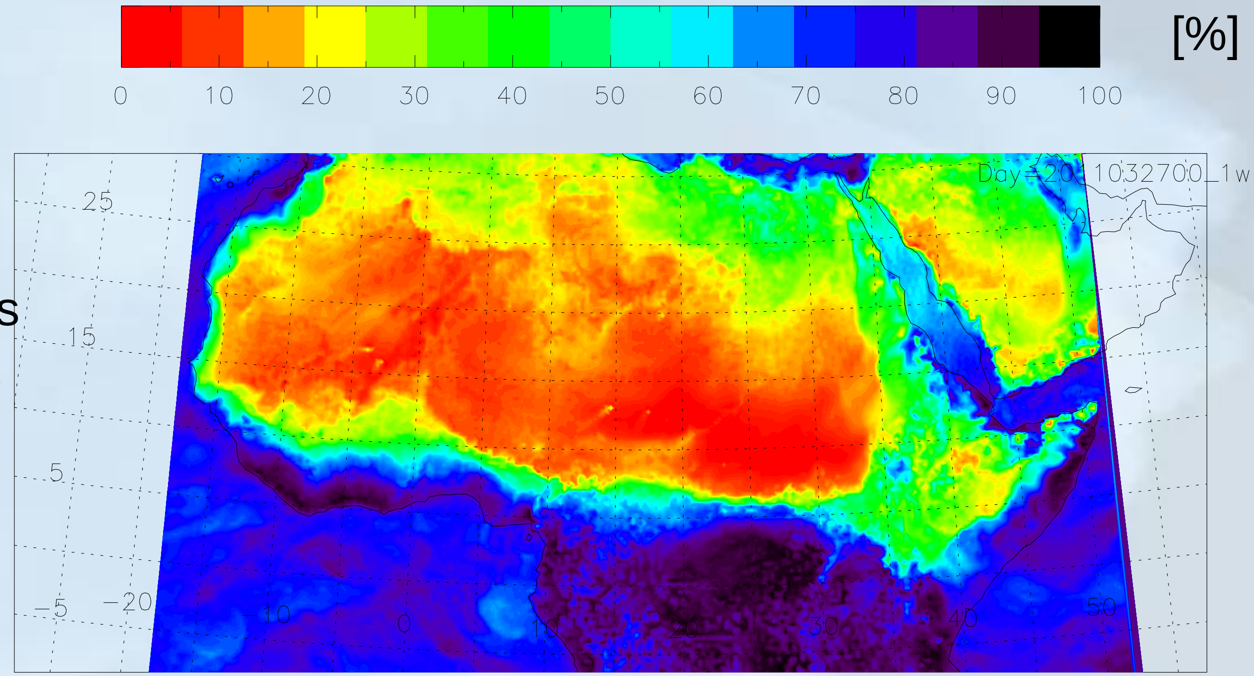
Probability of an epidemic (10 cases per 100,000) versus Relative Humidity over Africa's Meningitis Belt



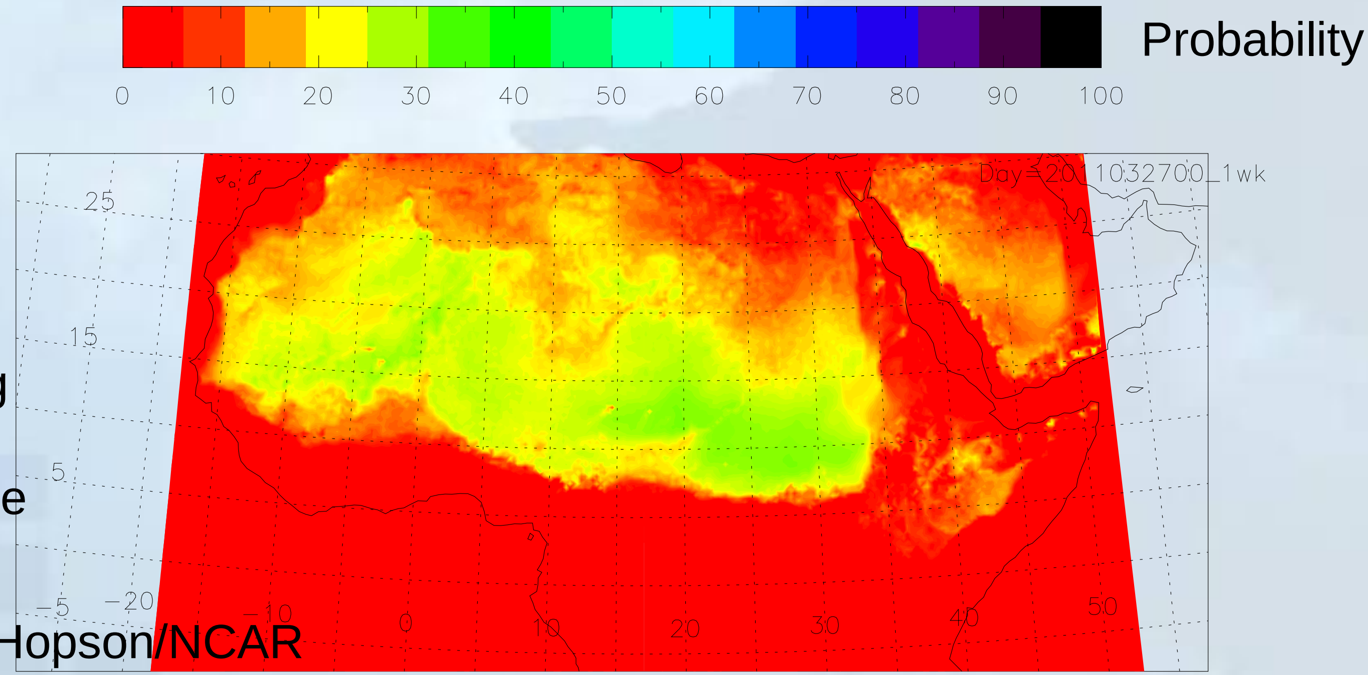


Slide courtesy of Tom Hopson/NCAR

Relative humidity across the Meningitis Belt forecast 1 week in advance …



… converted to probability of an epidemic occurring across the Belt 3 weeks in advance



Slide courtesy of Tom Hopson/NCAR

Next Steps – Clean Cook Stoves

Weather, Climate and Health Research Challenges and Steps Forward

Challenges to broader weather, climate and health research community

Health related systems are often oversimplified in models:

- Due to incomplete understanding of system components
- 'Giant leap' from vector (insect) modeling to disease modeling
- Need for even greater interdisciplinary efforts (has been improving)
- Due to limited 'predictor' data (i.e., air quality or human behavior)

Health 'predictand' (surveillance) data is incomplete or biased.

- Cannot develop robust models without adequate target data.
- Need longitudinal data, not just snapshots

Health 'predictor' data is highly uncertain or unavailable

- Especially true in regions of greatest risk (generally poorest)
- Behavioral/socio-economic data particularly sparse

Challenges to atmospheric science community

Collaborators want high resolution, high-fidelity, low cost data.

- We simply don't have observations or model data in most regions of greatest need. Remotely-sensed data fills some gaps.
- Atmospheric models have the potential to provide the necessary spatiotemporal resolution but we must address the expense issues.

Need to 'cross-train' meteorologists/climatologists so that they understand the complex needs of the health community. CDC Postdoctoral program at NCAR is a first step forward.

Steps Forward

Enhance opportunities for partnerships with stakeholders.

- This 'bottom up' approach is more comprehensive.
- Ensures that we address the problem in a manner that provides actionable information to the stakeholders.

Continue commitment to interdisciplinary research (it's working!)

- Ensure that early-career scientists have opportunities to be 'cross-trained' beyond their specialty

Enhance technology transfer from basic research to applications.

- While applications/impacts oriented research is on the rise, more could be done to leverage the results of basic research in this area.
- Bringing 'imperfect' systems operational (even in an experimental manner) will more rapidly lead to their development.

Support surveillance efforts.

- Surveillance provides the desperately needed 'target' data we need to develop predictive models.

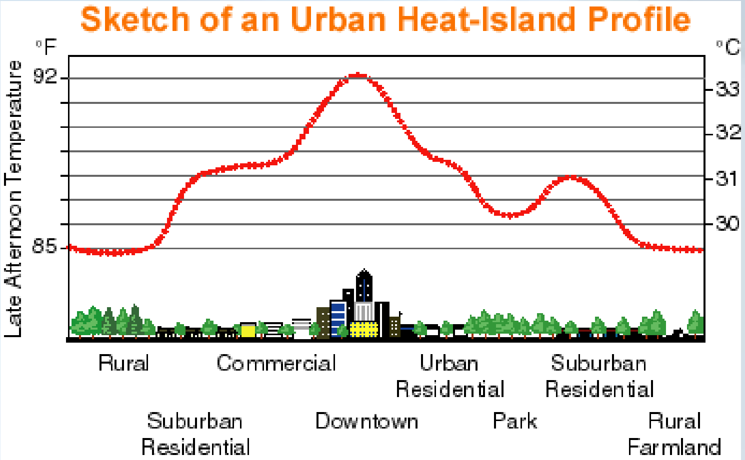
Thank you!

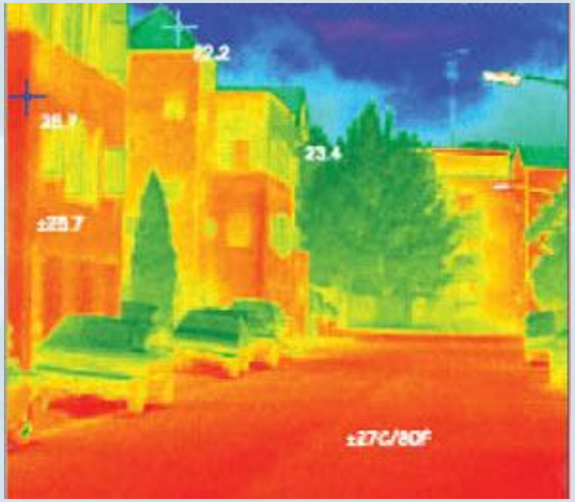
- Mary Hayden - mhayden@ucar.edu
- Andy Monaghan – monaghan@ucar.edu
- Olga Wilhelmi – olgaw@ucar.edu
- Raj Pandya – pandya@ucar.edu
- Tom Hopson – hopson@ucar.edu

Extra Slides

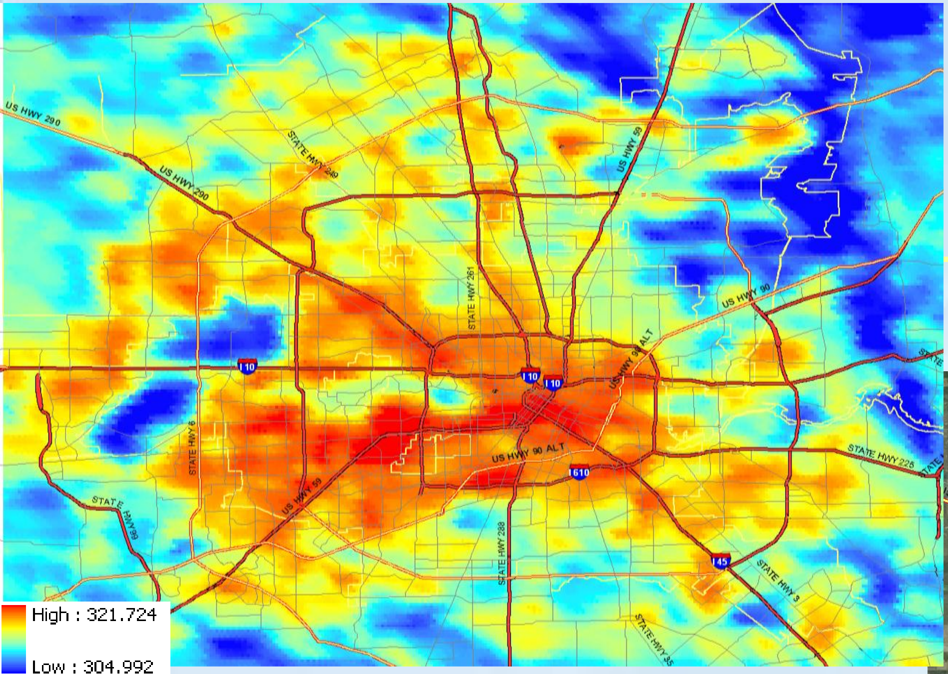
Urban Ecology and the UHI

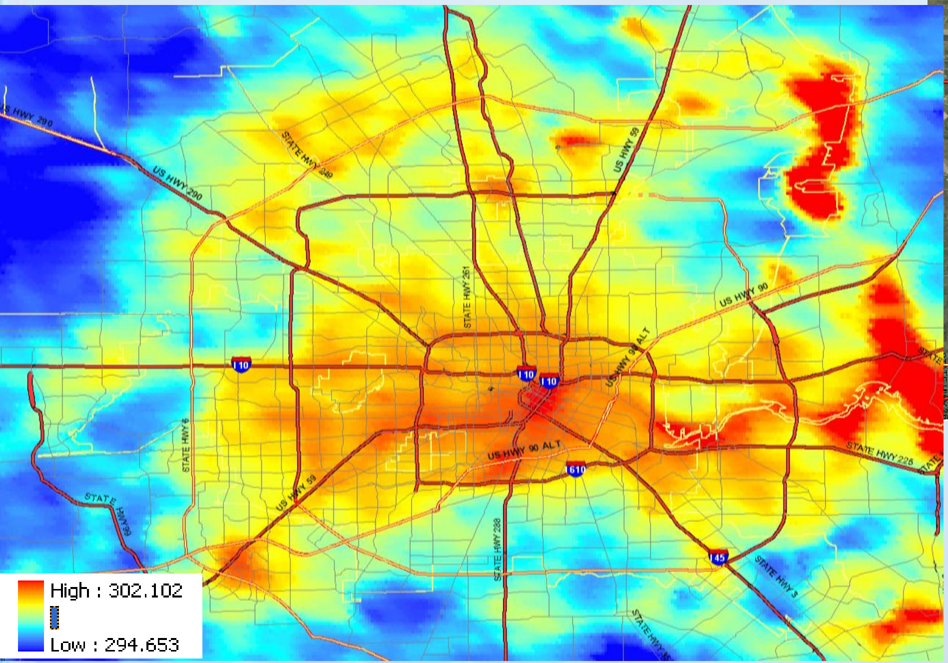
- **UHI created by two main factors:**
  1. Alterations to land cover: Replacement of natural land covers with sealed surfaces, street canyons that alter/block air flows, and reduction in long wave emissions from canyons
  2. Waste heat from heating and cooling systems
- **Improving representation of UHI through improved characterization of urban land cover**

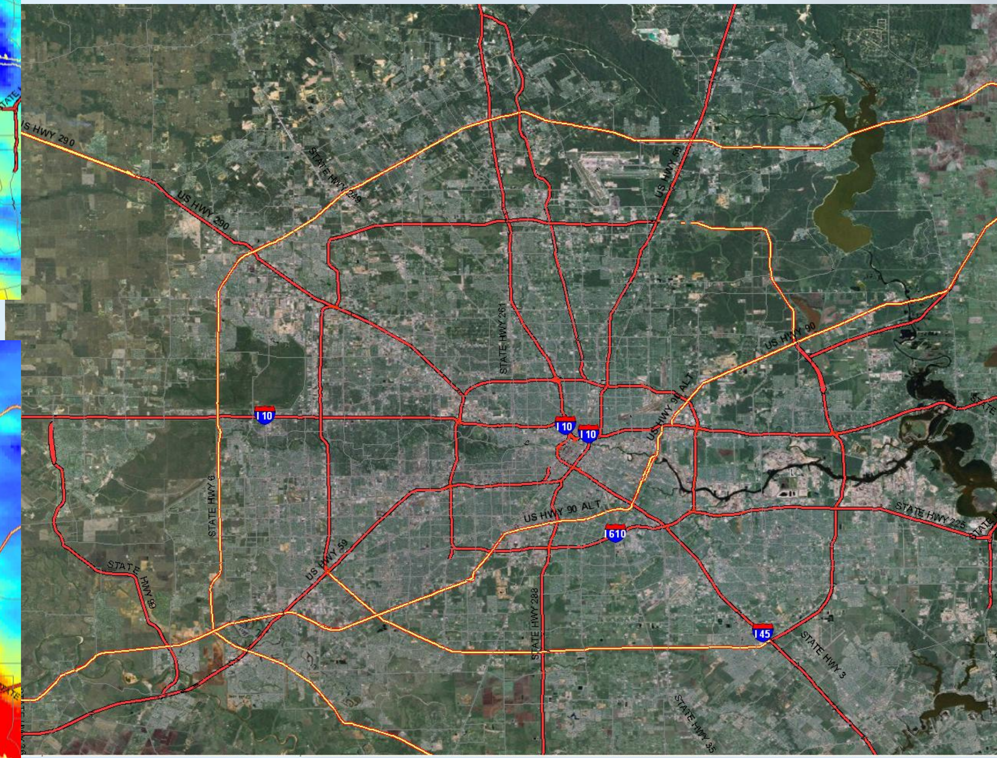




Remotely sensed UHI





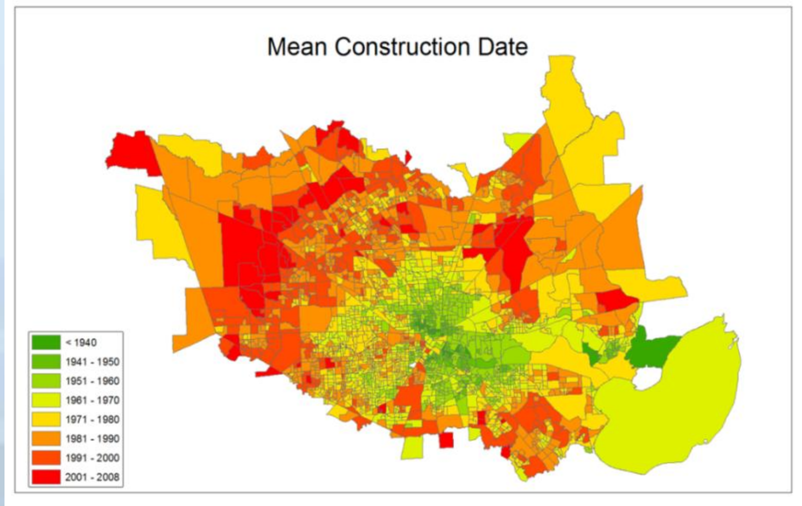


Sample of day and night time remote sensing (MODIS AQUA) cloud-free measurements during June-August 2006-2010 in Houston, TX

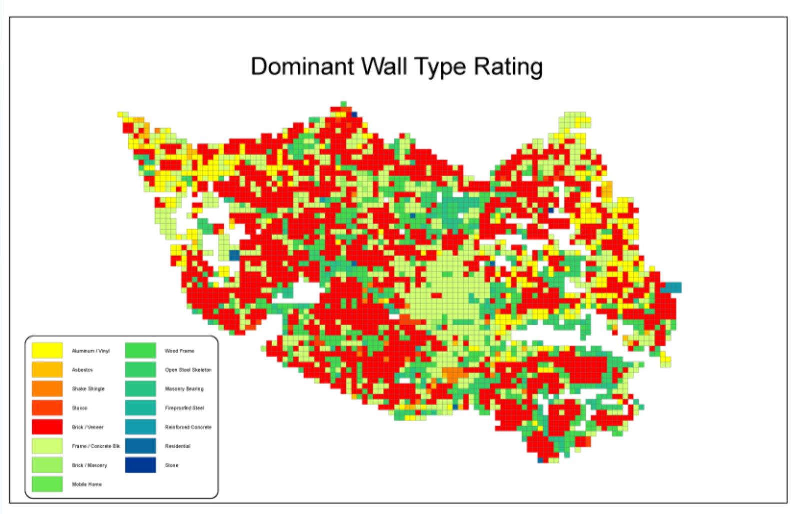
Improving representation of urban land cover

- **Building information from the Houston city housing database**
  - ~1.36 million parcel records;
  - ~1.07 million residential buildings
  - ~188,000 commercial
- **Use the database to determine the typical house properties by neighborhood (walls, roofs, windows)**

By Census Block Group



By WRF grid cell (~1km resolution)



Johan Feddema, U. Kansas

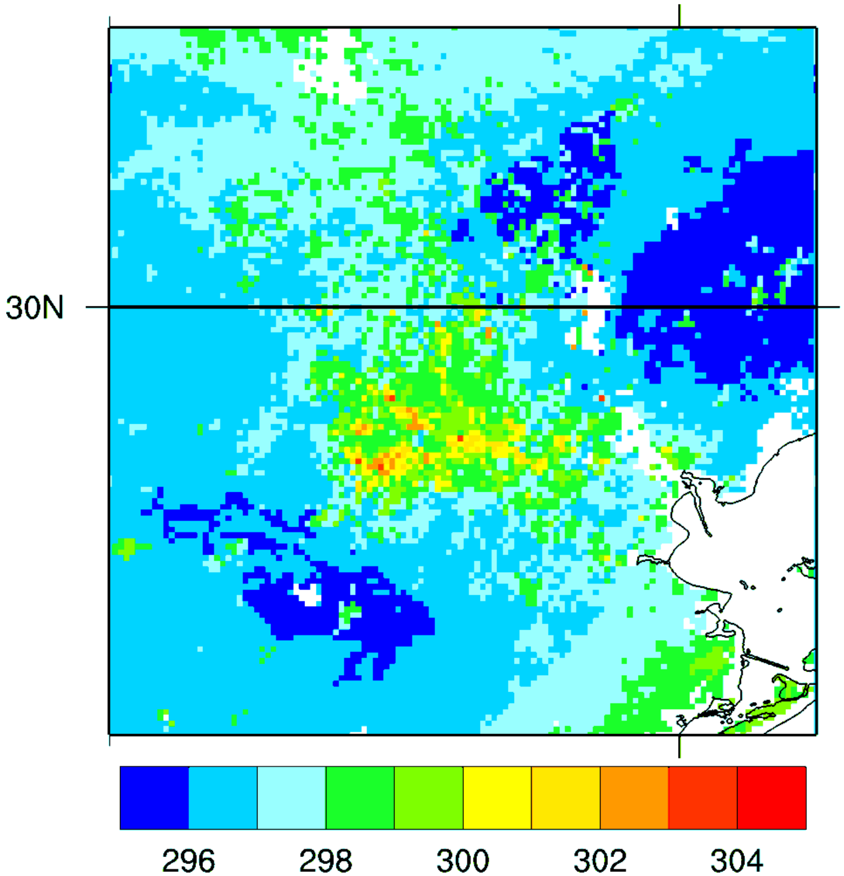
High resolution land surface model simulations of Houston's UHI

- **21 years of simulations: daily summary fields compiled from hourly output and used for vulnerability mapping**
  - Meteorological variables
  - Heat indices: NWS heat index, simplified wet bulb globe temperature, discomfort index, humidex, and apparent temperature.
- **Validation with weather stations and MODIS imagery**

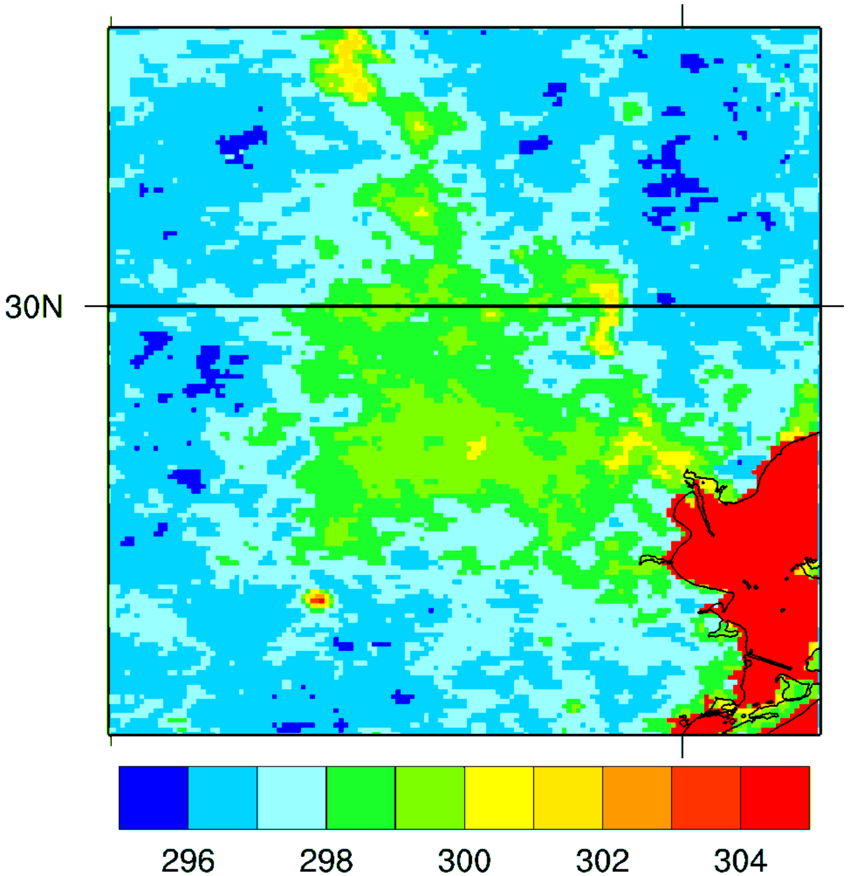
Andy Monaghan, NCAR

Nighttime UHI: 2006-08-21

HRLDAS (MODELED)



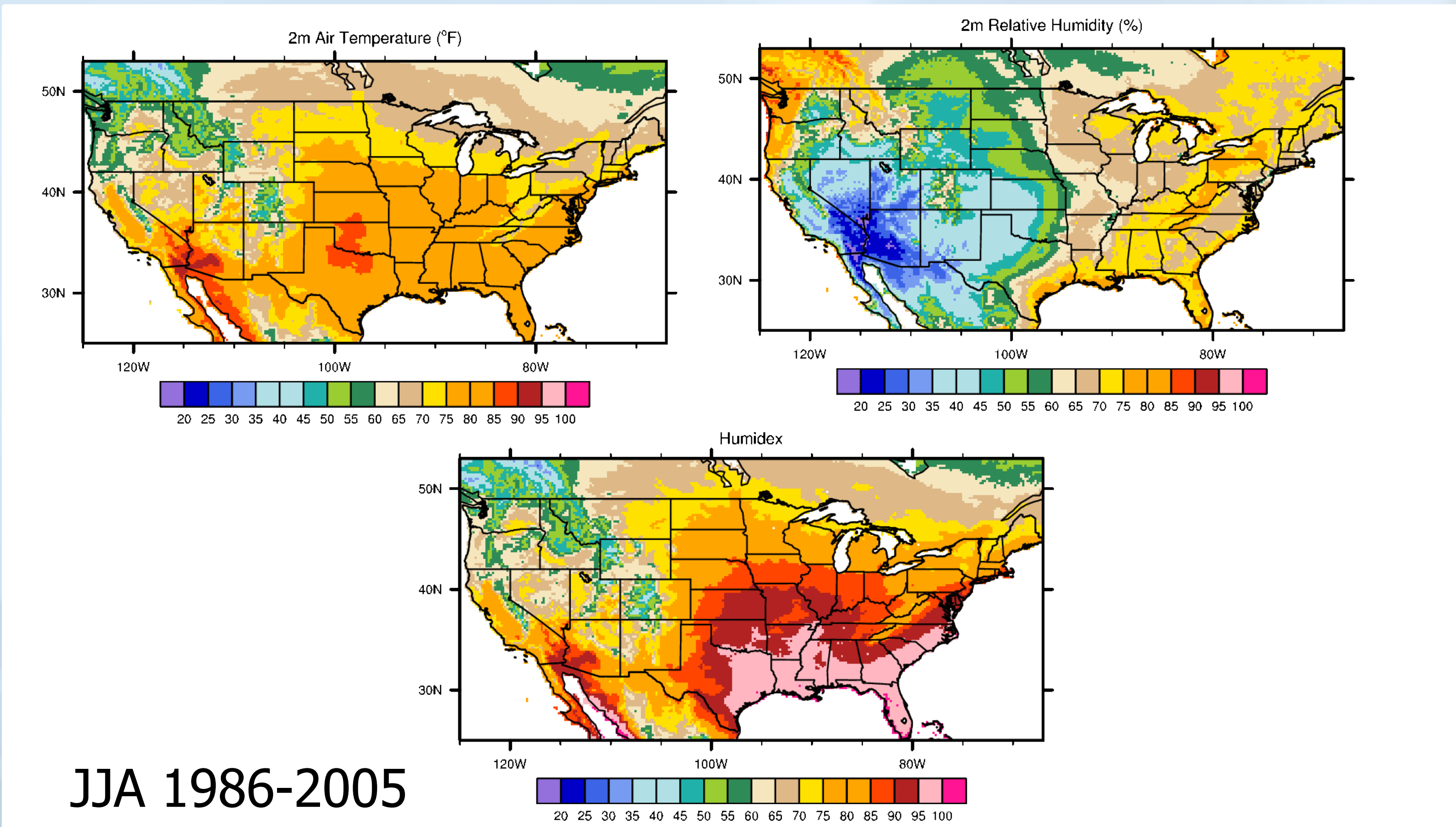
MODIS



Andy Monaghan, NCAR

Regional Climate (Heat) Modeling

- Regional simulations of heat waves using CLMU at 25 km
- Heat measures and future climate projections



Keith Oleson, NCAR

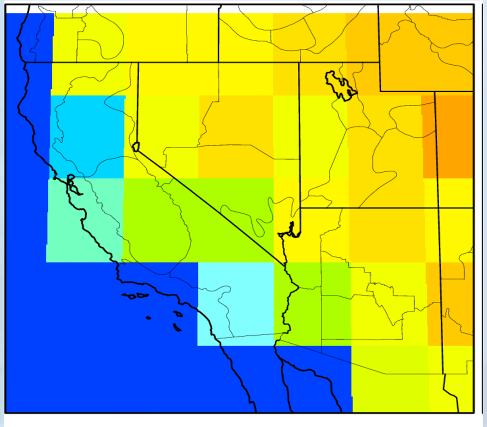
Knowledge Gaps

- Need better human, vector, and pathogen surveillance, particularly at the margins of transmission
- U.S./MX border is a prime example of an area at the geographic margins of current dengue transmission

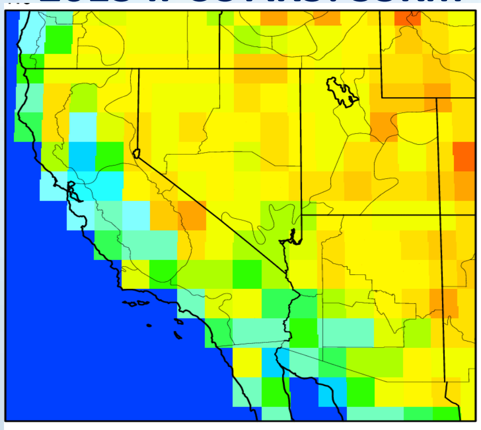
Knowledge Gaps

- **Need convergence of scales**
- **Transmission is local; sensitive to local variability**
  - small-scale differences in temperature and rainfall
  - human modification of the landscape
  - human behavior affecting vector-human contact
- **Climate is global, but low spatial resolution**

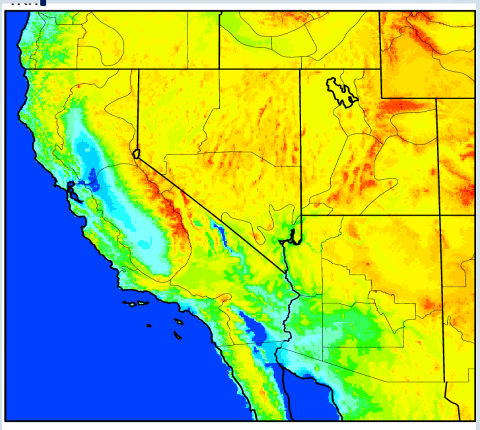
2007 IPCC AR4: 160KM Grid



2013 IPCC AR5: 55Km



Experimental NRCM: 4km

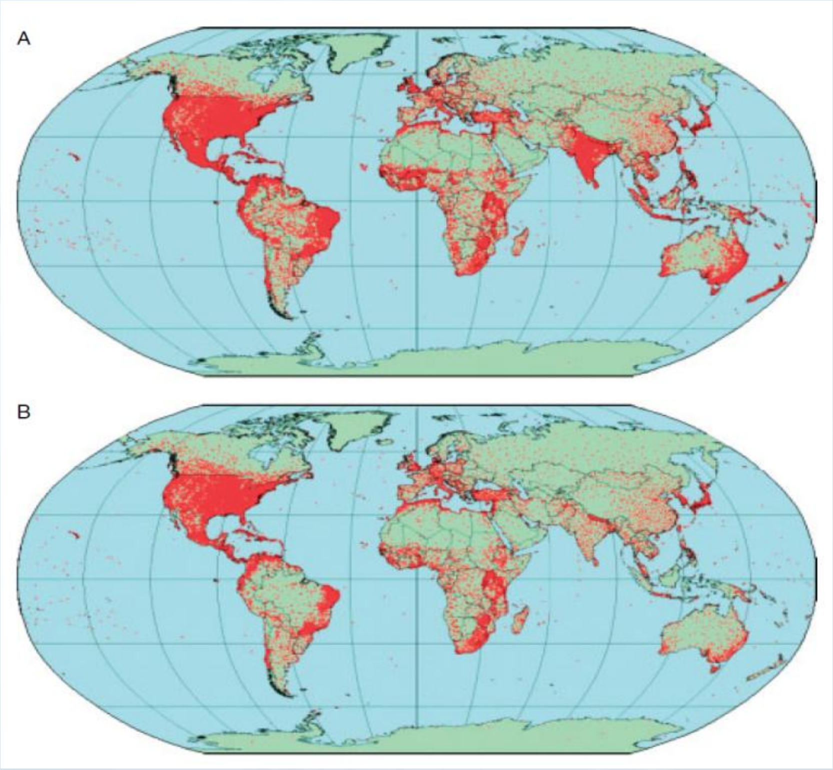


Knowledge Gaps

- **Need enhanced meteorological observation networks in most vulnerable locations (e.g., Africa)**

Surface Temperature

Precipitation



(Hijmans et al. IJOC, 2005)

Knowledge Gaps

- **Need long-term studies:**
  - Quantification of relationships between meteorological variables and vector or vector-borne pathogen occurrence
  - Examination of human behavioral influences on vector-human contact
  - Evaluation of consequences of shifting distributions of vectors and pathogens

Conclusions

- Climate change will likely alter the current distribution of vectors and pathogens
- However, predicting disease emergence due to climate change is less certain because of the complexity of the transmission dynamics