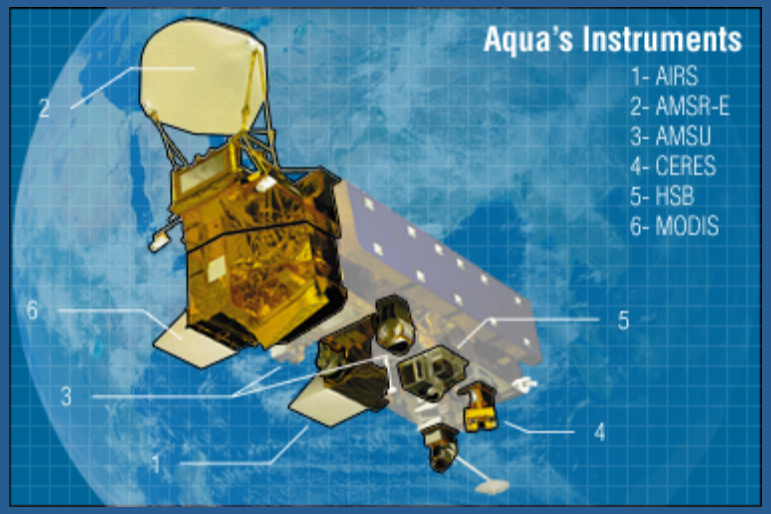
Enhanced Forecasting of Mosquito-Borne Disease Outbreaks Using AMSR-E

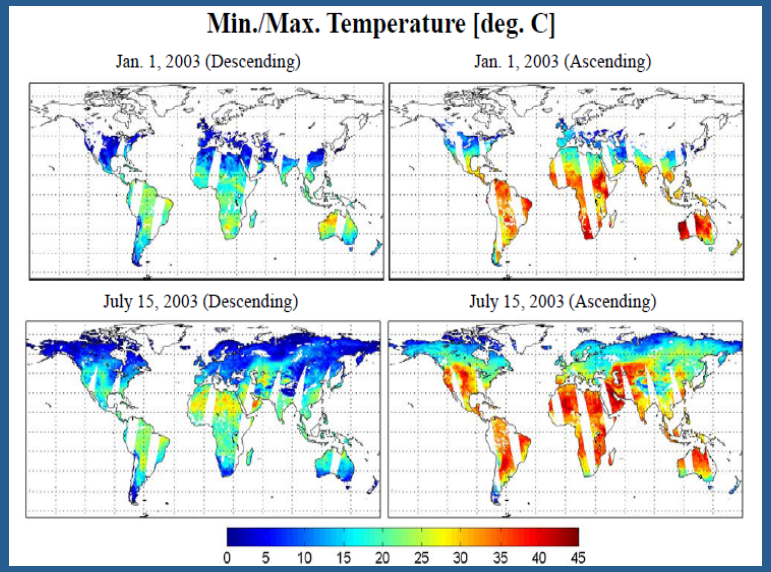
Mike Wimberly[1] (PI), Ting-Wu Chuang[1], Geoff Henebry[1], and John Kimball[2] (co-Is)

1 Geographic Information Science Center of Excellence, South Dakota State University,
2 Flathead Lake Biological Station, Division of Biological Sciences, The University of Montana

Background – AMSR-E Land Surface Parameters

- Satellite-retrieved geophysical parameters generated from the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) instrument on the Aqua satellite
  - Near-surface air temperature
  - Surface soil moisture
  - Fractional open water cover
  - Vegetation canopy opacity
- Daily record extends from 19 June 2002 to 27 September 2011
- Spatial resolution is 25 km





Research Objectives

- Objective 1: Develop statistical models of mosquito population dynamics and WNV incidence using AMSR-E land surface parameters.
- Objective 2: Compare the performance of the AMSR-E driven models with similar models derived from other sources of environmental monitoring data to quantify improvements in the forecasting of mosquito-borne disease outbreaks.
- Objective 3: Generate WNV risk forecasts from models based on AMSR-E variables, disseminate these predictions to public health practitioners, and obtain qualitative feedback on the value and utility of these predictions.

Objectives 1 and 2

Remote Sensing of Environment 125 (2012) 147–156

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

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

Satellite microwave remote sensing for environmental modeling of mosquito population dynamics

Ting-Wu Chuang [a,*], Geoffrey M. Henebry [a], John S. Kimball [b], Denise L. VanRoekel-Patton [c], Michael B. Hildreth [d,e], Michael C. Wimberly [a]

[a] Geographic Information Science Center of Excellence, South Dakota State University, Brookings, SD 57007, United States
[b] Flathead Lake Biological Station, Division of Biological Sciences, The University of Montana, Polson, MT 59860, United States
[c] City of Sioux Falls Health Department, Sioux Falls, SD 57104, United States
[d] Department of Biology and Microbiology, South Dakota State University, Brookings, SD 57007, United States
[e] Department of Veterinary & Biomedical Sciences, South Dakota State University, Brookings, SD 57007, United States

ARTICLE INFO

Article history:
Received 15 May 2012
Received in revised form 19 July 2012
Accepted 21 July 2012
Available online xxxx

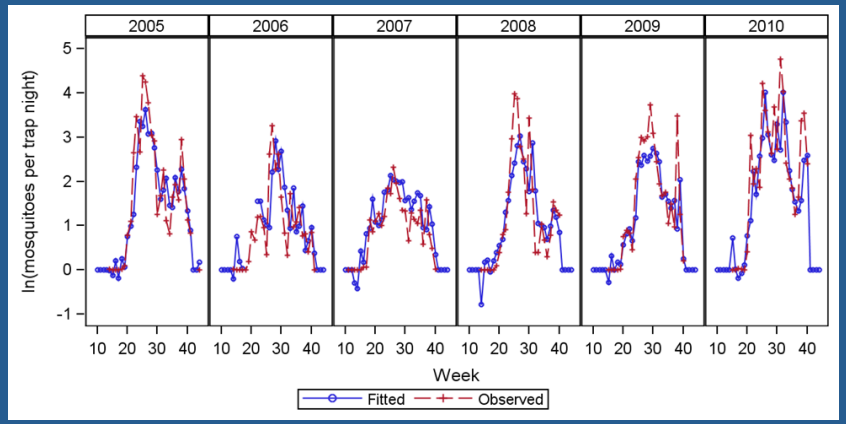
Keywords:
AMSR-E
Weather Station
West Nile Virus
Mosquito
Public Health

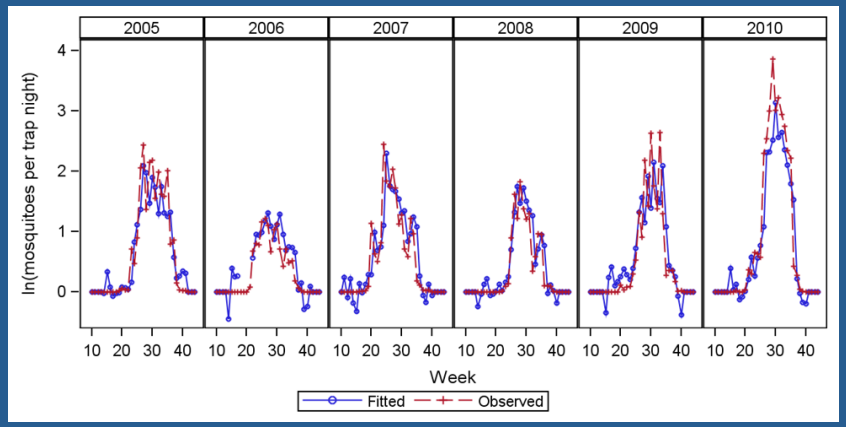
ABSTRACT

Environmental variability has important influences on mosquito life cycles and understanding the spatial and temporal patterns of mosquito populations is critical for mosquito control and vector-borne disease prevention. Meteorological data used for model-based predictions of mosquito abundance and life cycle dynamics are typically acquired from ground-based weather stations; however, data availability and completeness are often limited by sparse networks and resource availability. In contrast, environmental measurements from satellite remote sensing are more spatially continuous and can be retrieved automatically. This study compared environmental measurements from the NASA Advanced Microwave Scanning Radiometer on EOS (AMSR-E) and *in situ* weather station data to examine their ability to predict the abundance of two important mosquito species (*Aedes vexans* and *Culex tarsalis*) in Sioux Falls, South Dakota, USA from 2005 to 2010. The AMSR-E land parameters included daily surface water inundation fraction, surface air temperature, soil moisture, and microwave vegetation opacity. The AMSR-E derived models had better fits and higher forecasting accuracy than models based on weather station data despite the relatively coarse (25-km) spatial resolution of the satellite data. In the AMSR-E models, air temperature and surface water fraction were the best predictors of *Aedes vexans*, whereas air temperature and vegetation opacity were the best predictors of *Cx. tarsalis* abundance. The models were used to extrapolate spatial, seasonal, and interannual patterns of climatic suitability for mosquitoes across eastern South Dakota. Our findings demonstrate that environmental metrics derived from satellite passive microwave radiometry are suitable for predicting mosquito population dynamics and can potentially improve the effectiveness of mosquito-borne disease early warning systems.

Overview of Major Results

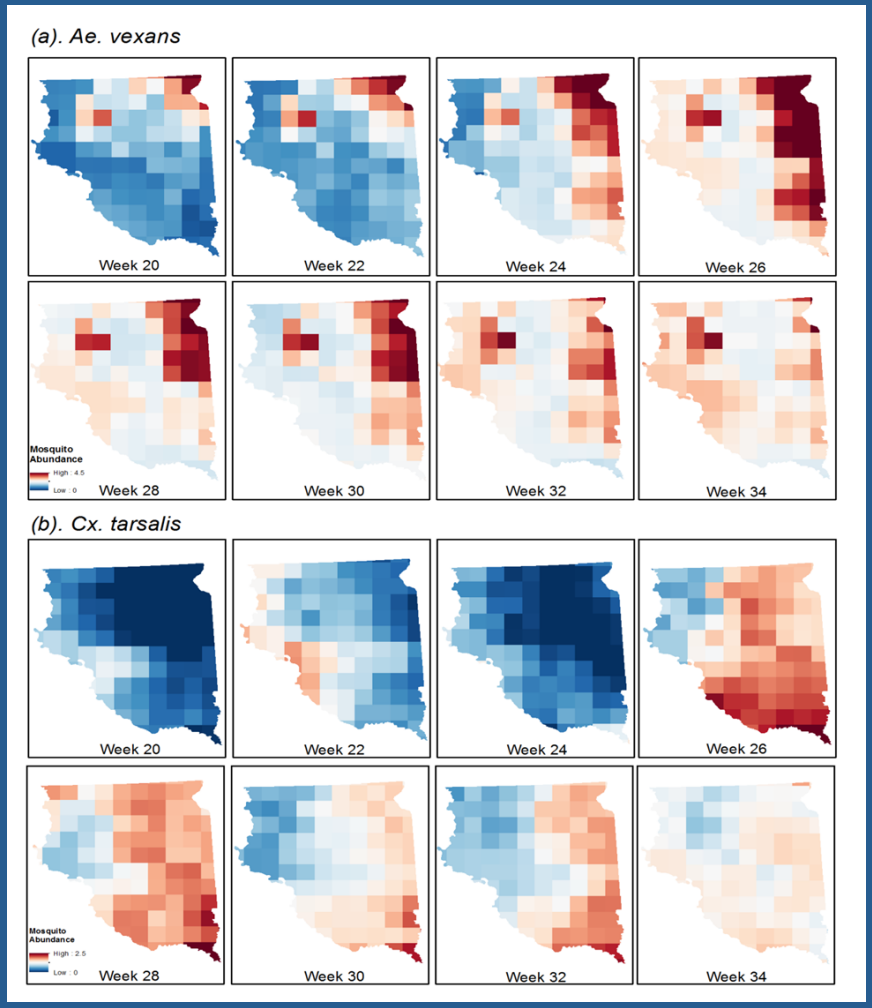
- Compared environmental models based on AMSR-E land surface parameters versus meteorological variables
- Models based on AMSR-E had better fits
  - Fractional water strongly associated with *Aedes vexans*
  - Vegetation opacity improved the fit of the *Culex tarsalis* model





Overview of Major Results

- Model evaluation
  - Cross-validation indicated high potential for predicting mosquito activity at the same location where the model was parameterized
  - Validation against data from an independent site indicated moderate potential for predicting seasonal and interannual variability at different locations

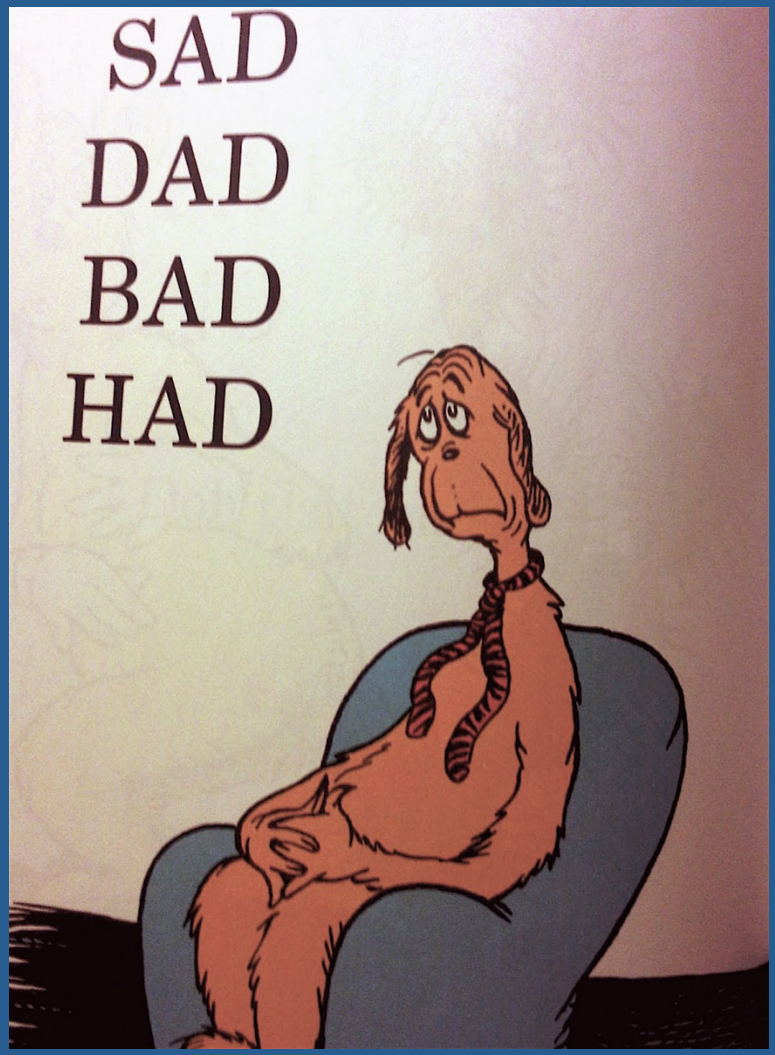


Summary – Mosquito Population Models

- AMSR-E land surface parameters were as effective as weather station data for modeling mosquitoes
- Unique measurements of biophysical Earth-surface characteristics - not simply a remote “proxy” for ground data
- Integrates information over broad spatial extents

Objective 3

The AMSR-E antenna stopped spinning at 0726GMT Oct 4, 2011 most likely due to aging lubricant in the mechanism. AMSR-E is currently not producing any data. The Aqua spacecraft accommodated the spin-down, which occurred over a period of about 25 minutes, and continues to operate normally, with all other instruments functioning in science mode. NASA will work with JAXA to understand the condition of the AMSR-E instrument and possible future steps.

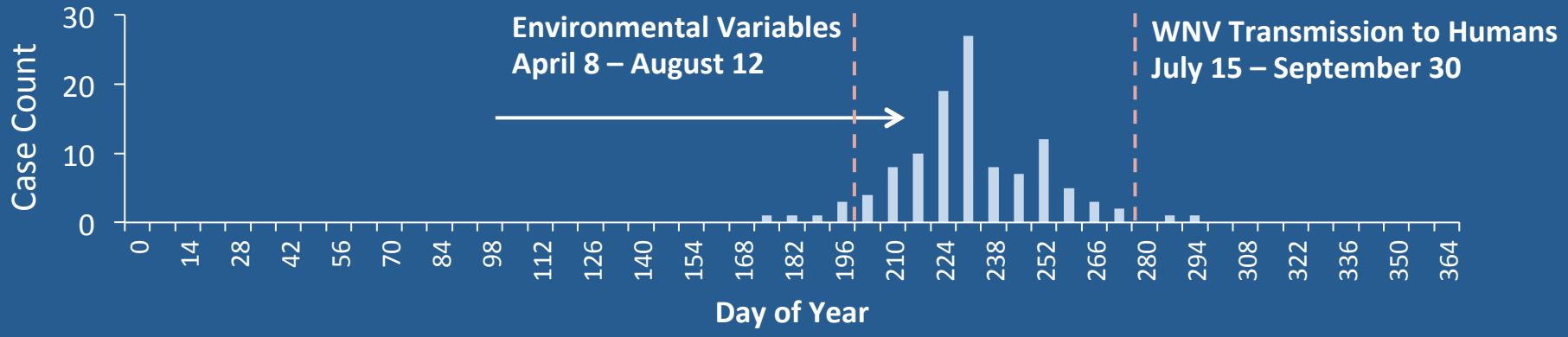


Dealing with the Pitfall

- Short-term: Develop and test forecasting models based on MODIS and other sources of optical-IR RS data.
- Long term:
  - WindSat microwave radiometer has similar channels and an overlapping record with AMSR-E
  - AMSR2 launched in May 2012 onboard GCOM-W1
  - Potential for continuous, uninterrupted brightness temperature and land parameter retrievals

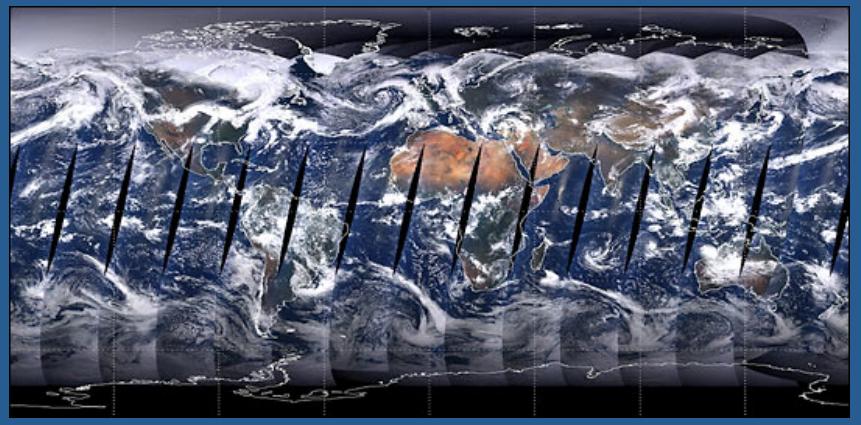
Modeling WNV Incidence in Humans Across the Northern Great Plains

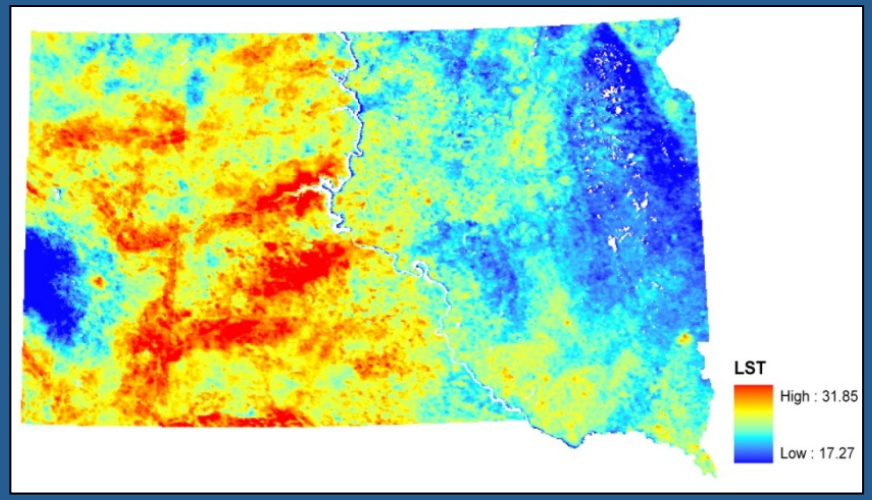
- Response Variable – Log relative risk (LRR) computed for each county in each year
- Predictor Variables – Cumulative environmental metrics for different days of the year (DOY 105-217 at 8-day intervals).
- Fit generalized additive models (GAMs) to historical environmental and case data
- Predict using 2011 environmental data



Sources of Remote Sensing Data

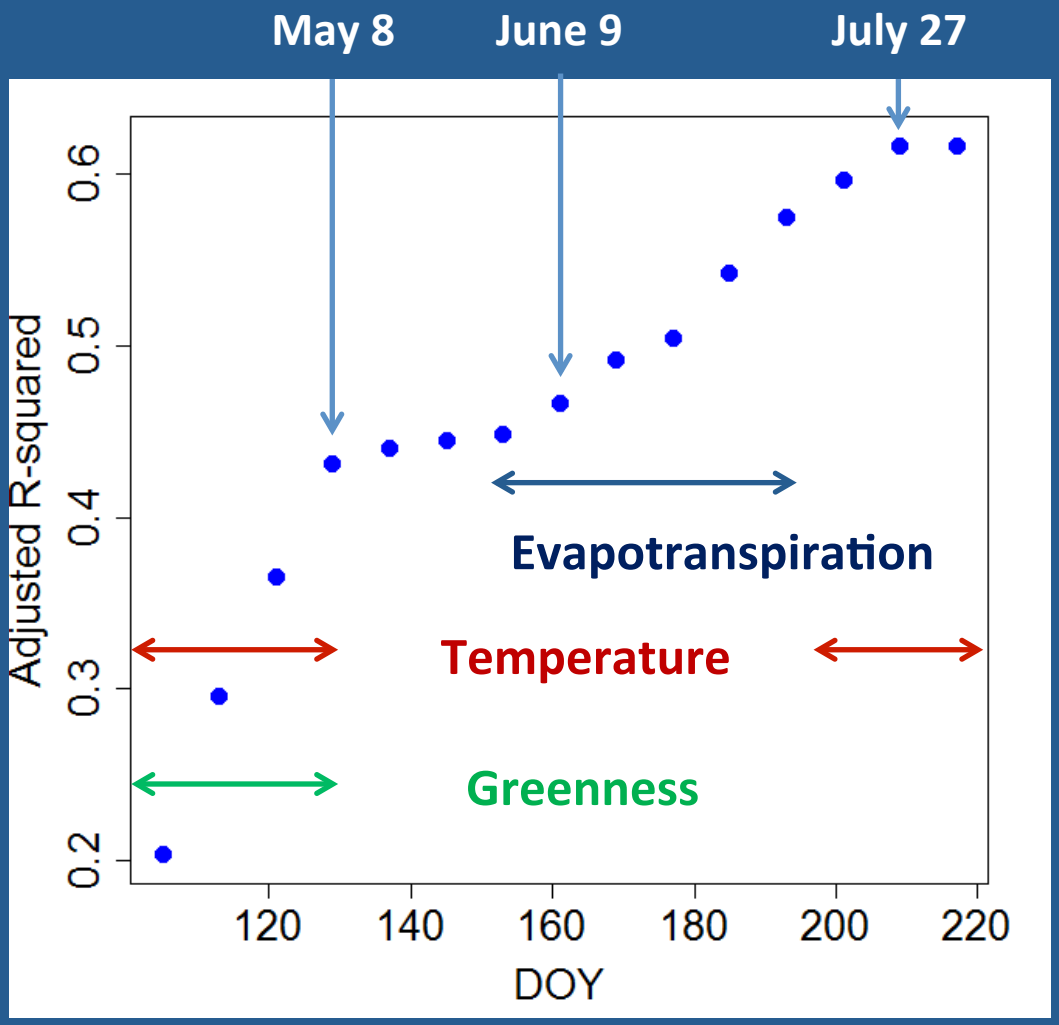
- Greenness
  - NDVI from MODIS nadir BRDF-adjusted reflectance
- Temperature
  - MODIS/Terra Land surface temperature
- Evapotranspiration
  - Simplified surface energy balance method





Land surface temperature in early July in SD, 2010 (MOD11A2 product)

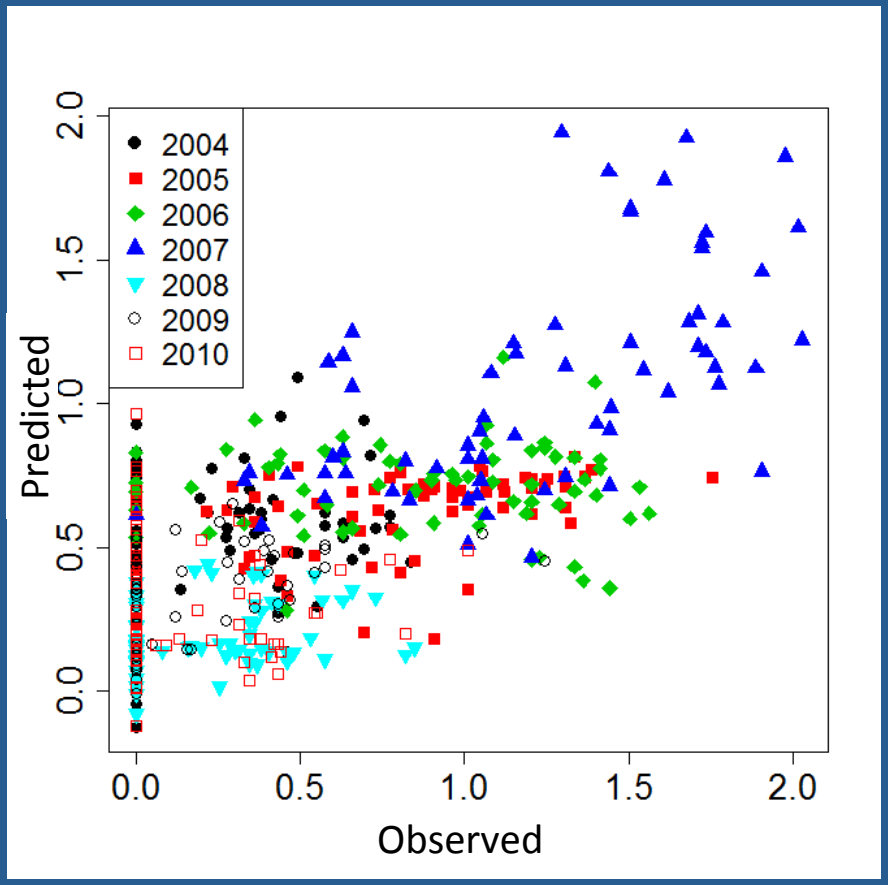
Model Fit Improves as Environmental Data from Later in the Season is Included



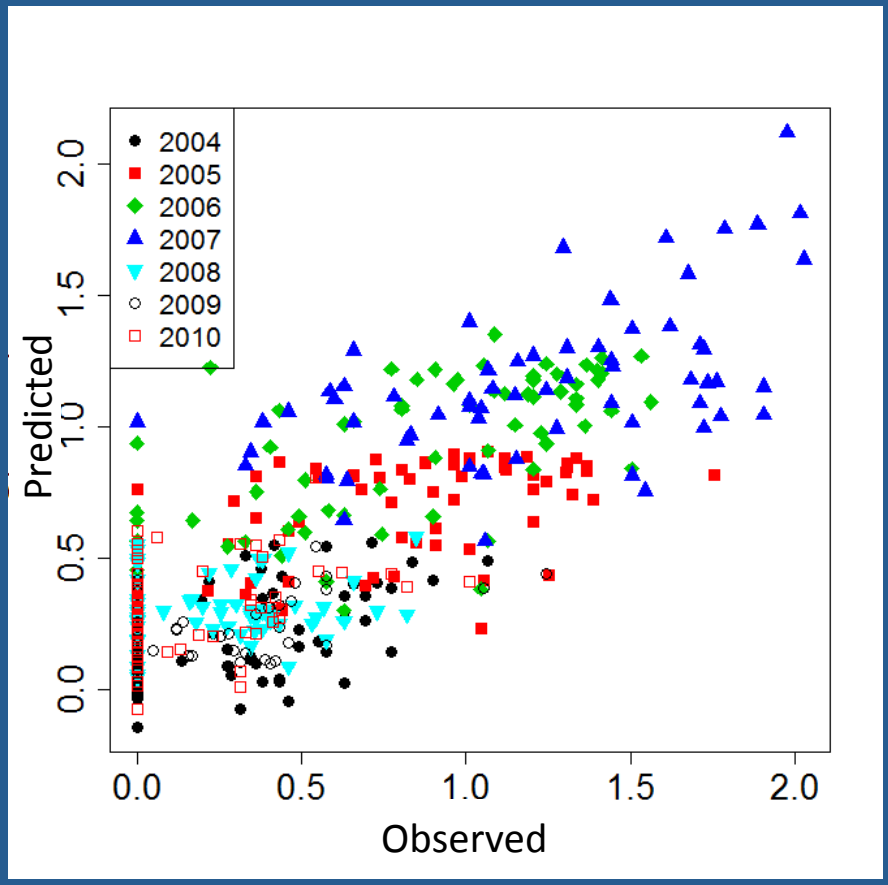
- Greenness and temperature measure onset of spring in early season models
- Temperature and evapotranspiration measured accumulated degree days and moisture in the late-season models

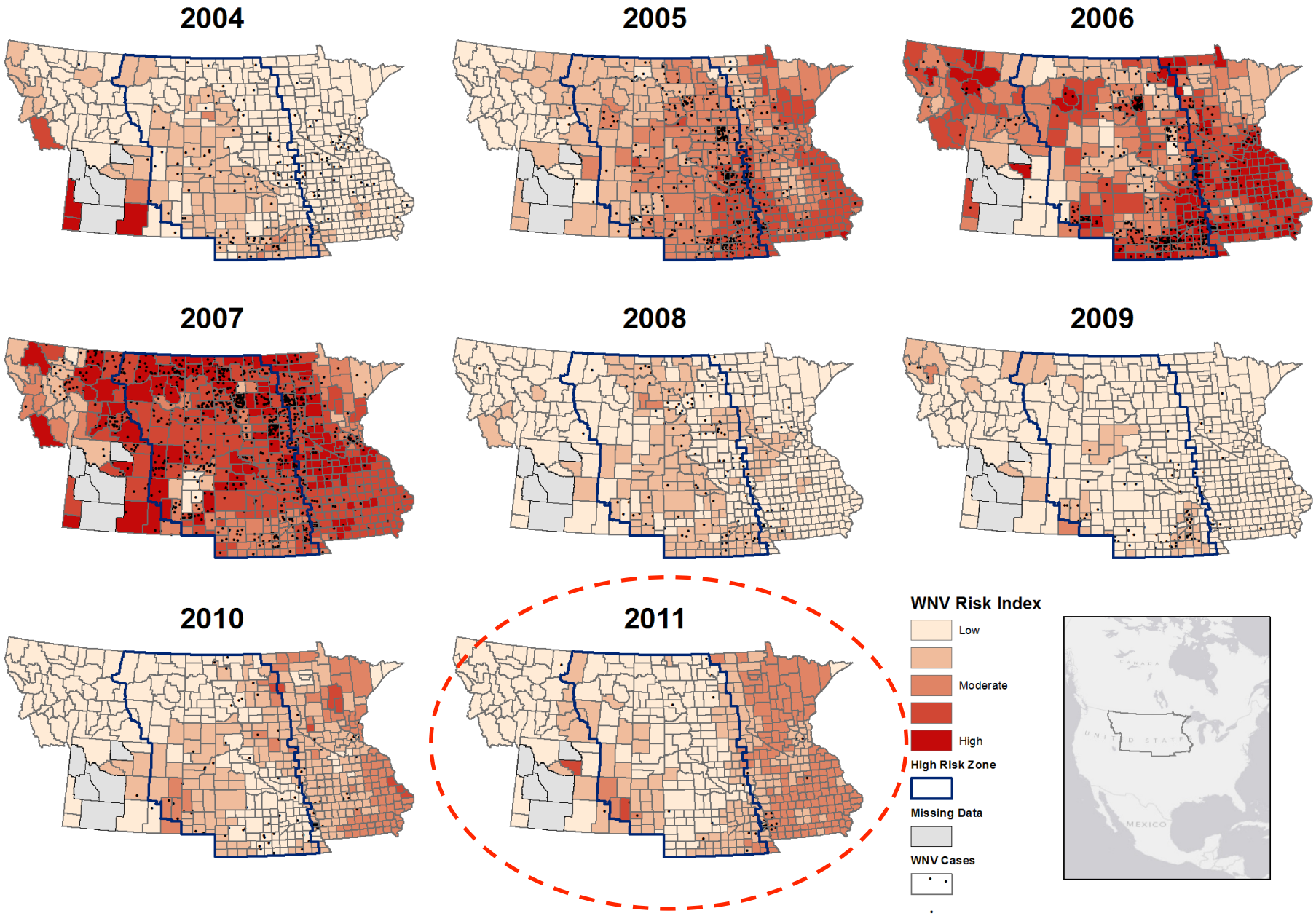
Model Fit Improves as Environmental Data from Later in the Season is Included

Model fit using environmental data through May 15



Model fit using environmental data through July 18



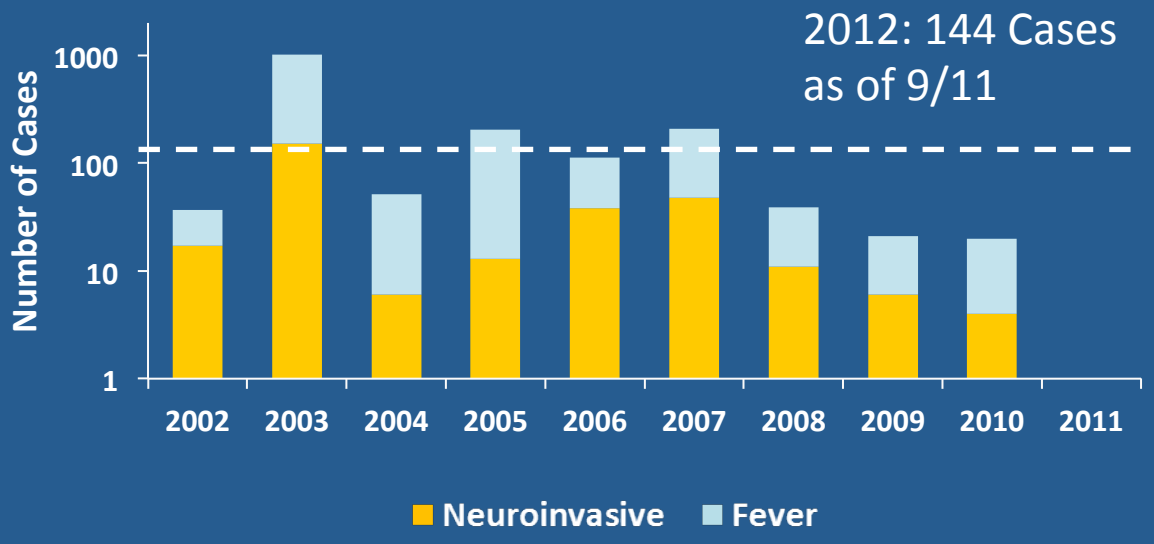

2004
2005
2006
2007
2008
2009
2010
2011
WNV Risk Index
Low
Moderate
High
High Risk Zone
Missing Data
WNV Cases
CANADA
UNITED STATES
MEXICO

2012 Predictions

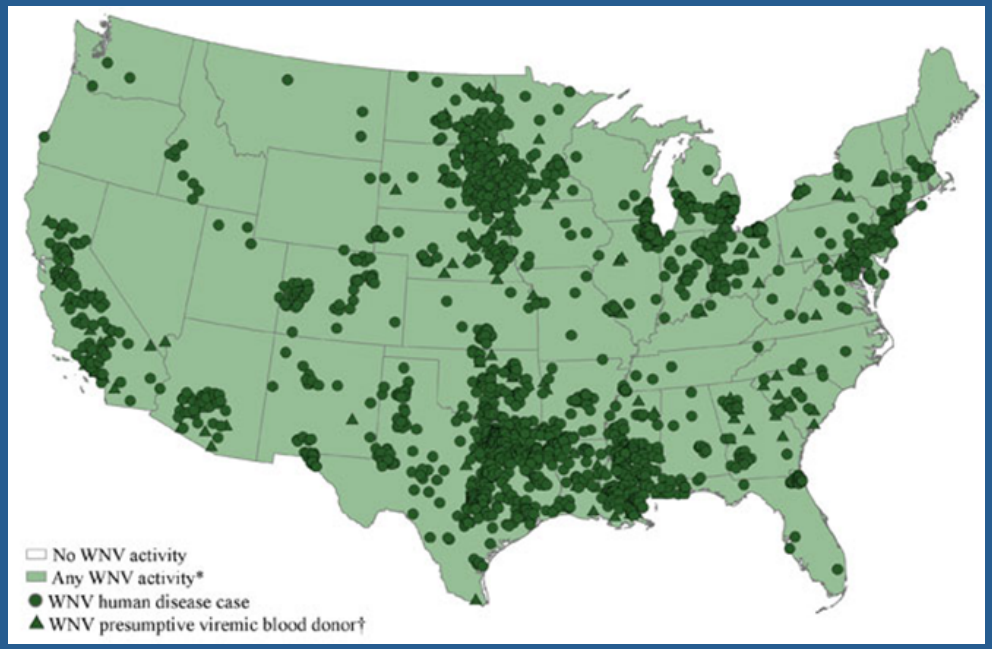
August 2010

September 2012

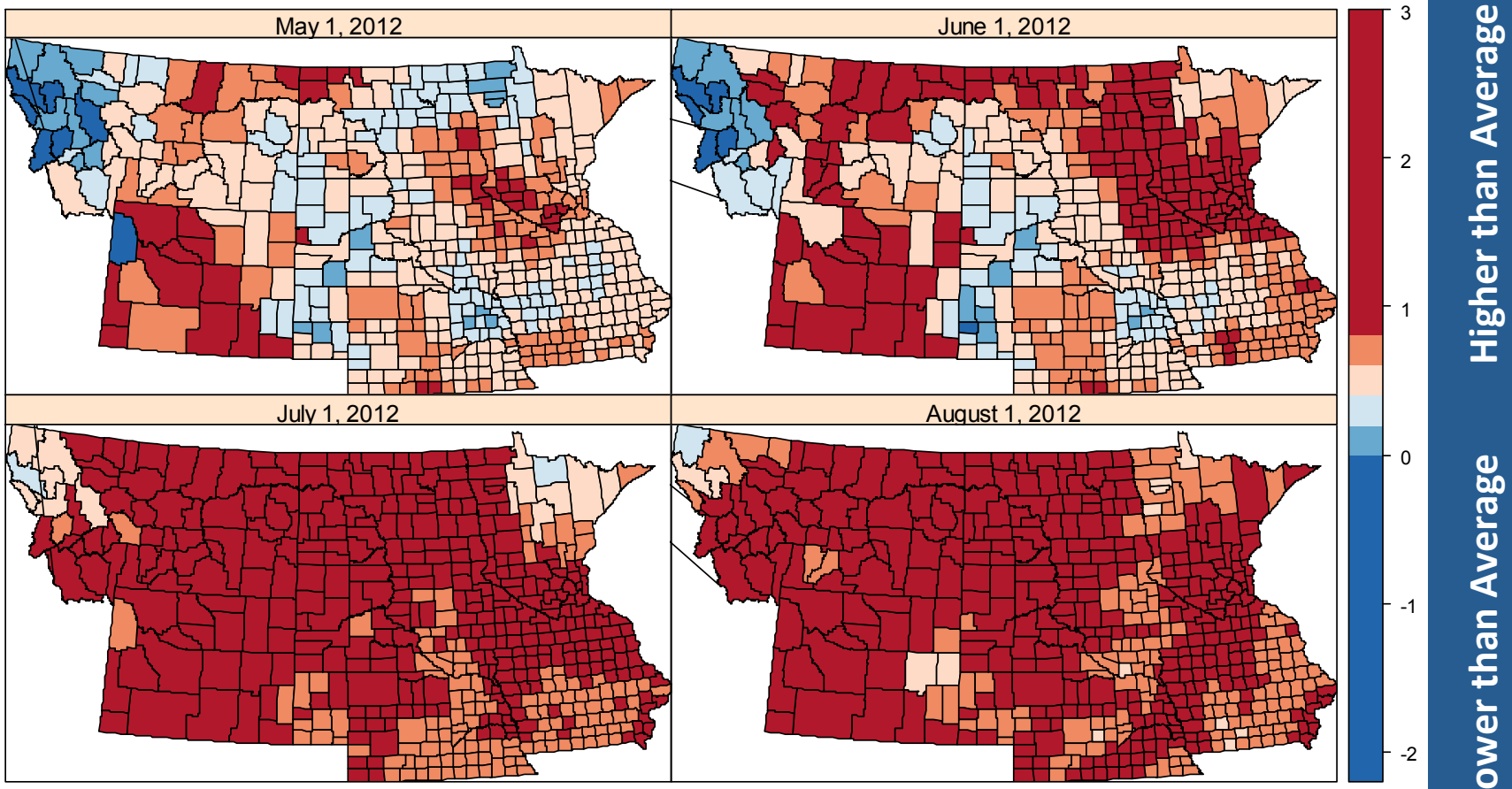
South Dakota



West Nile virus (WNV) activity reported to ArboNET, by state, United States, 2012 (as of September 11, 2012)



WNV Relative Risk Forecasts for the 2012 Transmission Season

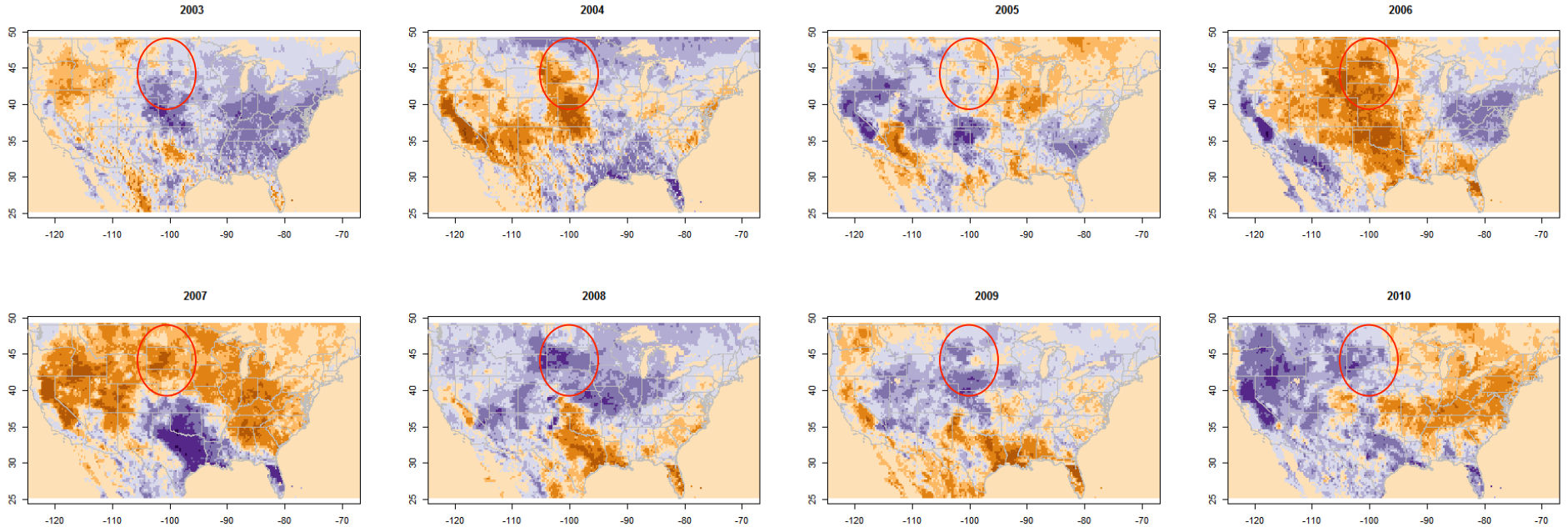


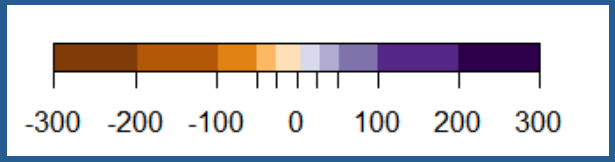
Summary

- Strong temperature effects are predictive of outbreaks at a regional level
  - *Culex tarsalis* development rates, survival, biting rates
  - WNV extrinsic incubation period
- Surface moisture and breeding habitats may help to delineate the spatial locations of outbreaks
  - Non-linear relationships with moisture
  - Relationships not always consistent from year to year
- Host (bird) community composition and immunity status is also important
- Chuang, T., and M. C. Wimberly (*In Press*) Remote Sensing of Climatic Anomalies and West Nile Virus Incidence in the Northern Great Plains of the United States. *PLoS One*.

AMSR-E Air Temperature Anomalies

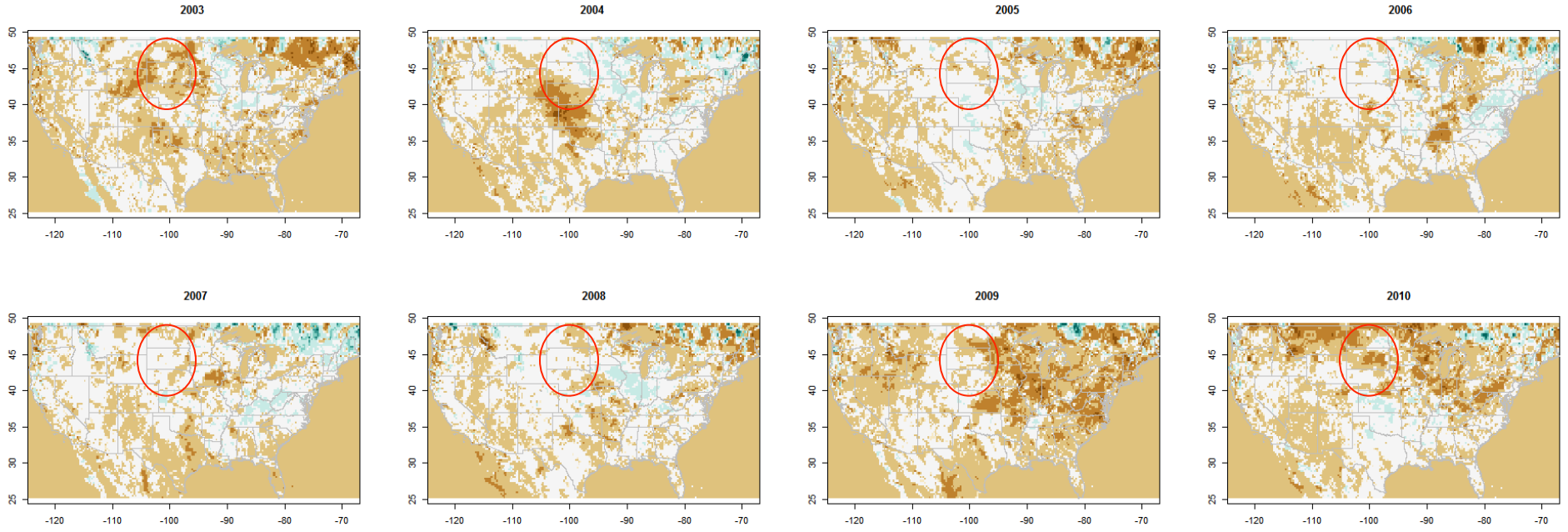
Accumulated Degree Days (Through July 1st) Above the 14.3° C Threshold for Virus Development

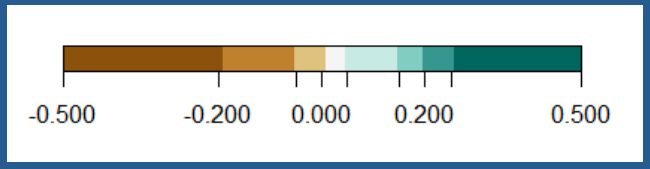




AMSR-E Soil Moisture Anomalies

Volumetric Soil Moisture for the first week in July





Completing the Feasibility Study

- 60% of funds expended, on track to spend all funds and complete work by project end date (3/31/2012)
- Follow-up meeting with SD Department of Health to discuss prospects for WNV forecasting
- Update models of WNV human disease with AMSR-E land surface parameters (though 2011) and compare with models based on optical-IR data
- Examine associations between environmental anomalies and WNV outbreaks at a national level

Acknowledgements

- Sioux Falls Health Department
  - Denise Patton
- South Dakota Department of Health
  - Jennifer Griesse
  - Christine Hockett
  - Lon Kightlinger
- South Dakota State University
  - Alemayehu Midekisa, GIScCE
  - Aashis Lamsal, GIScCE
  - Mike Hildreth, Depts. of Biology/Microbiology and Veterinary Science
  - Yi Liu, Dept. of Electrical Engineering and Computer Science
  - Jim Wilson, Plant Science Department
- USGS Center for EROS
  - Gabriel Senay
- Funding
  - NIH/NIAID (R01-AI079411)
  - NASA (NNX11AF67G)

http://globalmonitoring.sdstate.edu/eastweb/