



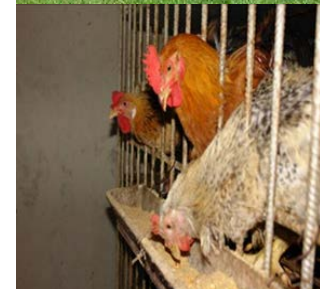
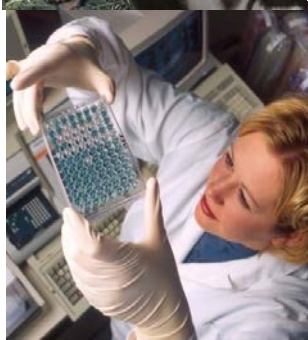
United States Department of Agriculture

Veterinary Services

The Impact of Movements and Animal Densities on Continental Scale Cattle Disease Outbreaks in the U.S

Daniel A Grear, PhD
Ecologist

U.S. Department of Agriculture
Animal and Plant Health Inspection Service
Veterinary Services
STAS
October 18, 2014



- **Data:**
Interstate Cattle Transport Network
- **Scaling up & filling in:**
Nation-wide Cattle Movements
- **Framework for Disease Spread**



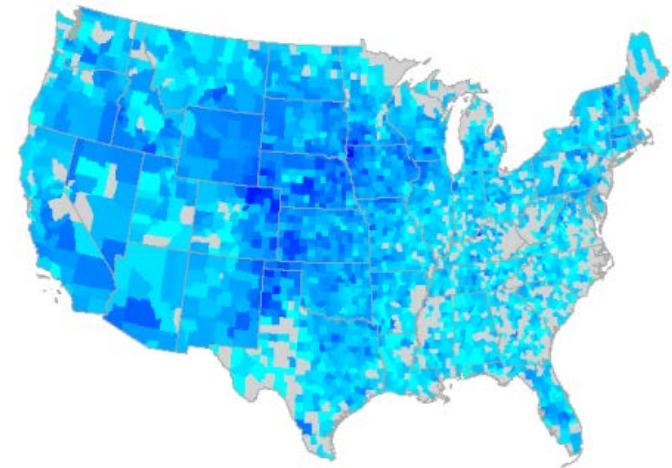
- 10% of 2009 Cattle Export ICVIs
- 19,000+ ICVIs
- 2433 counties from 49 states
- 1500+ student hours
- Currently expanding to multiple years



Data Match Multiple Descriptions of US System

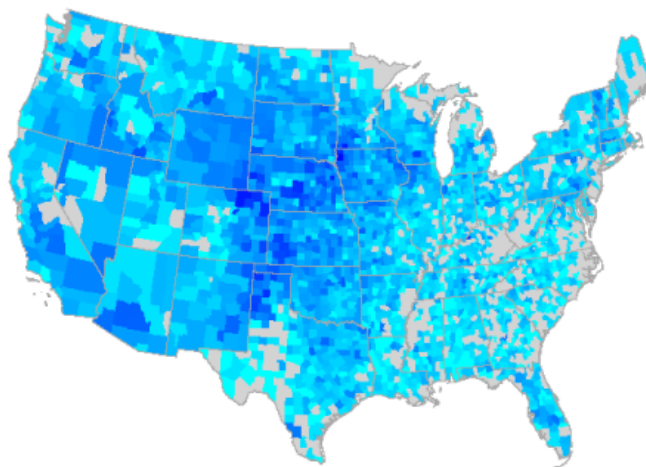
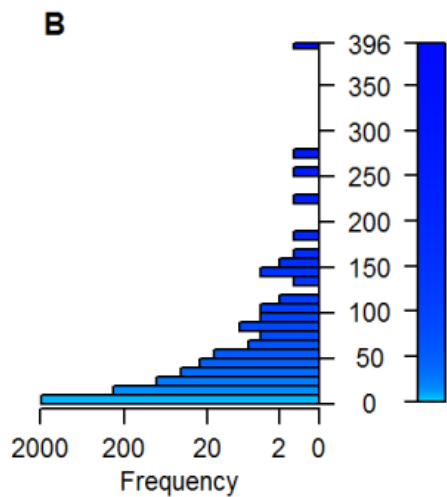
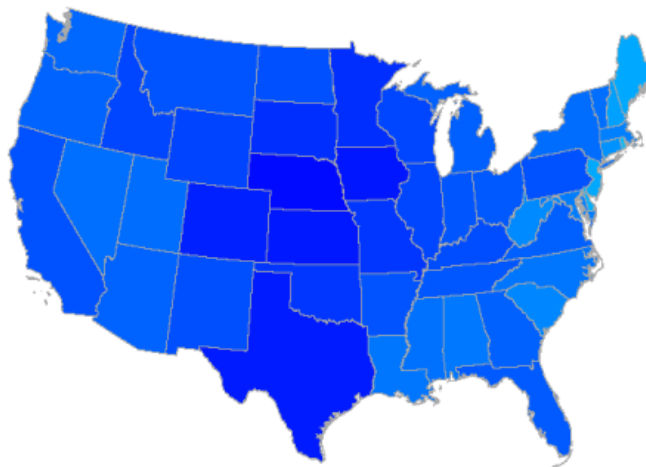
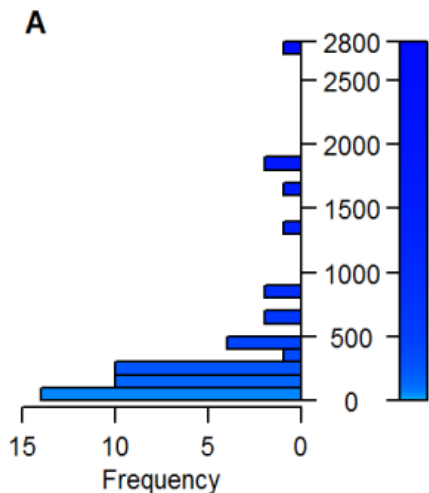
- Dominated by shipments to and from Great Plains states
- 45% feeding / 17% breeding / 7% show
- Cattle amassed in large central feeding system from numerous, relatively small holdings (59% ≤ 50 head)
- Beef/dairy shipments matches US herd (3:1, NASS)

Number of In-Shipments



Data Suggest County Scale

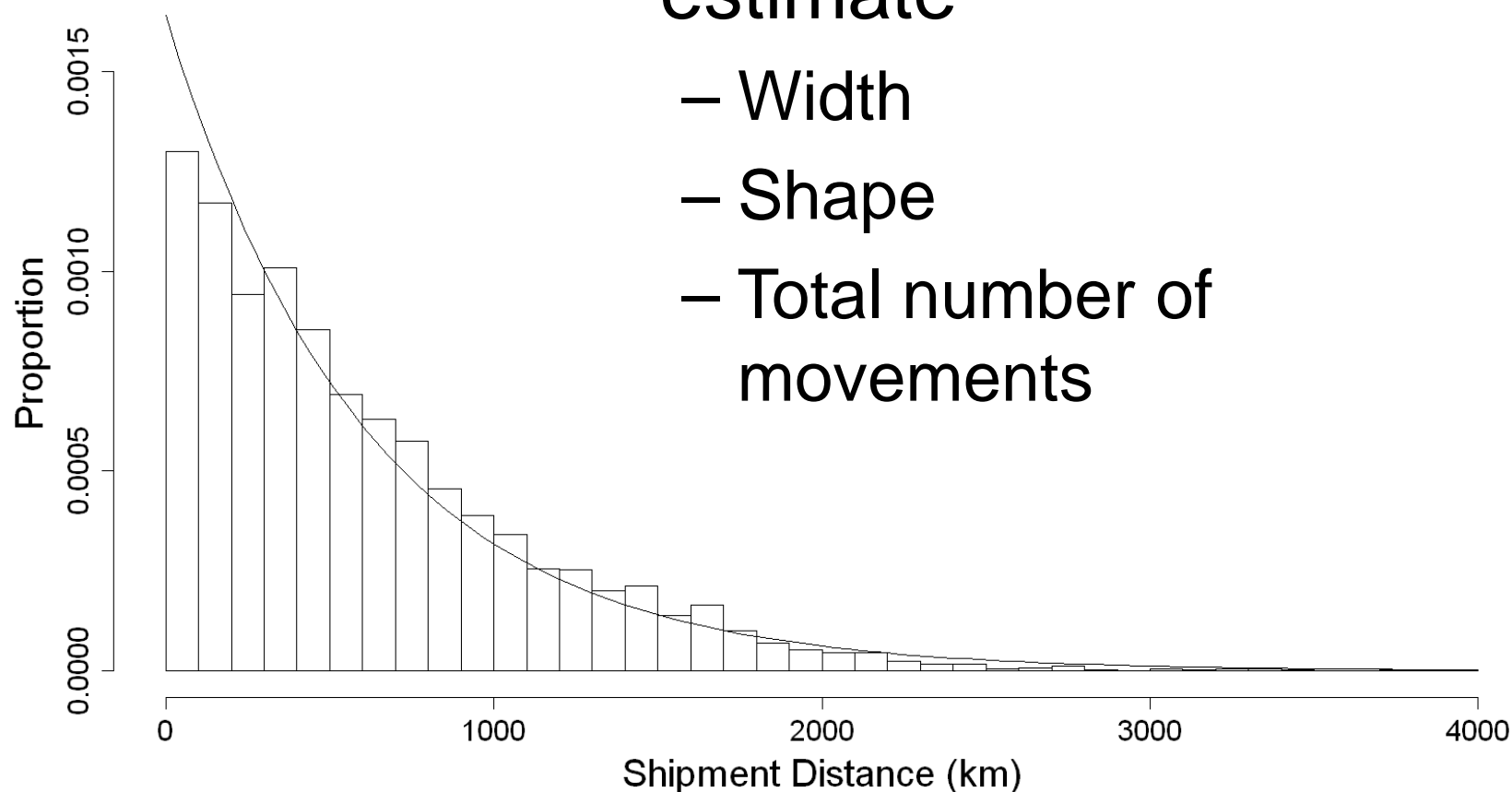
Number of In Shipments



- Scale up 10% sample to full network
- Fill in unobserved intrastate movements
- Incorporate uncertainty- benefits of Bayesian approach
- Prediction

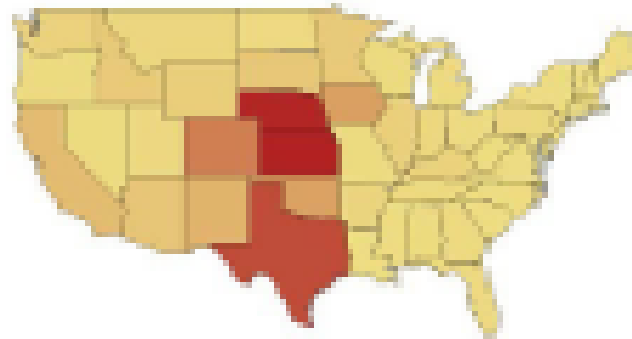
- Kernel parameters to estimate

- Width
- Shape
- Total number of movements

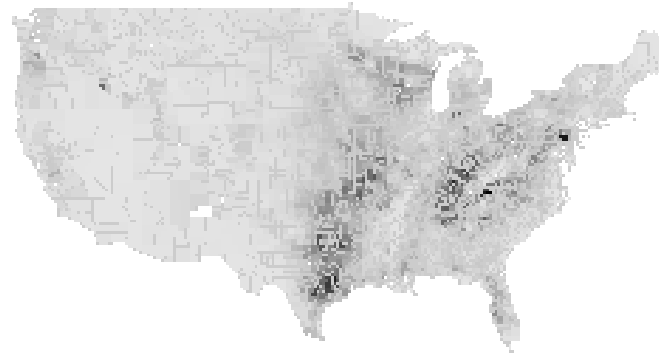


- Spatially explicit, coarse summary of cattle industry

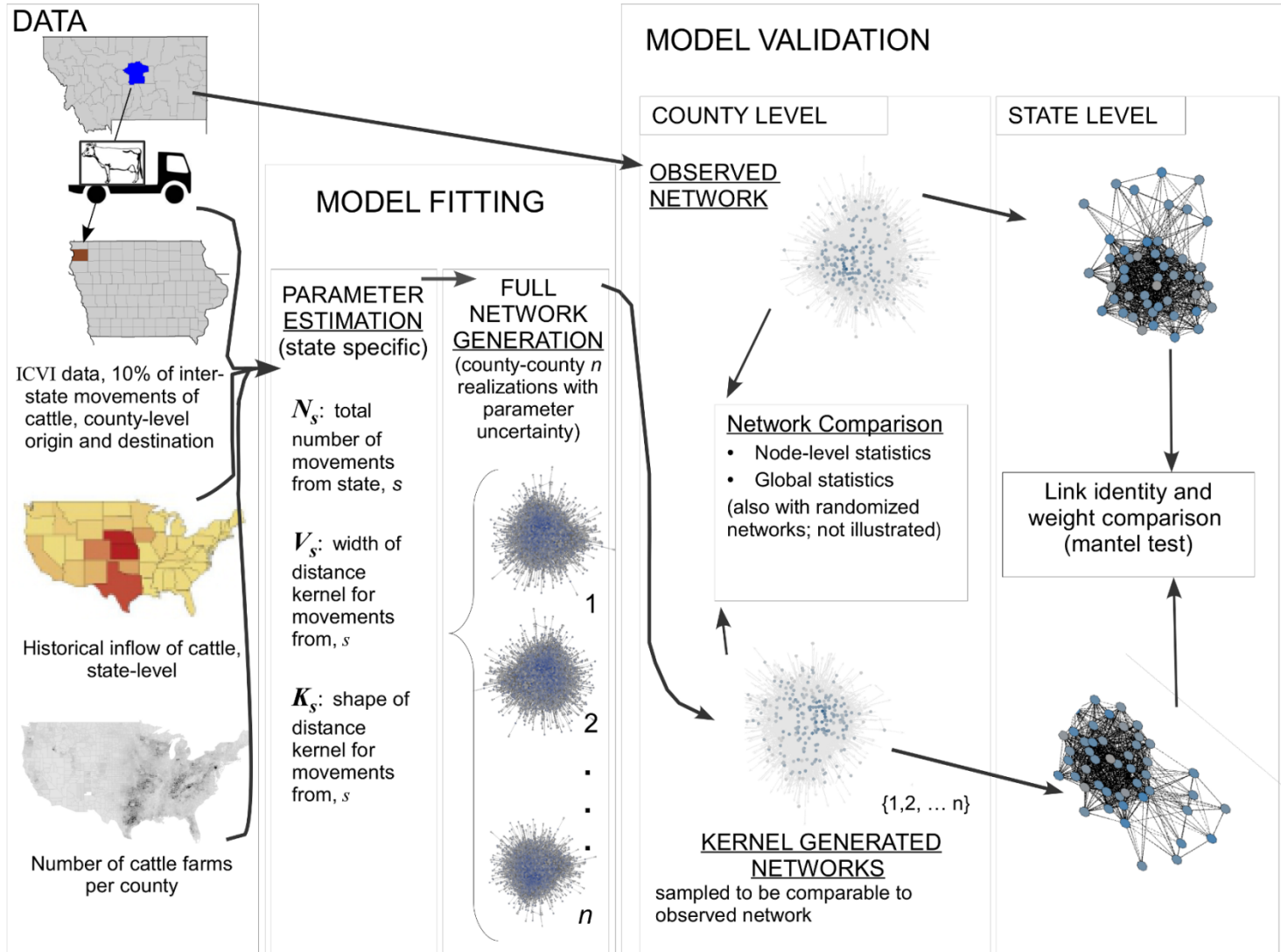
Historical
cattle inflow



Farm number
per county

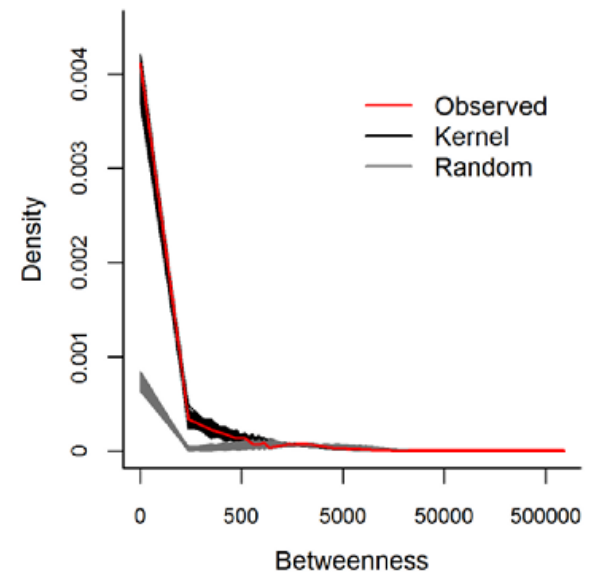
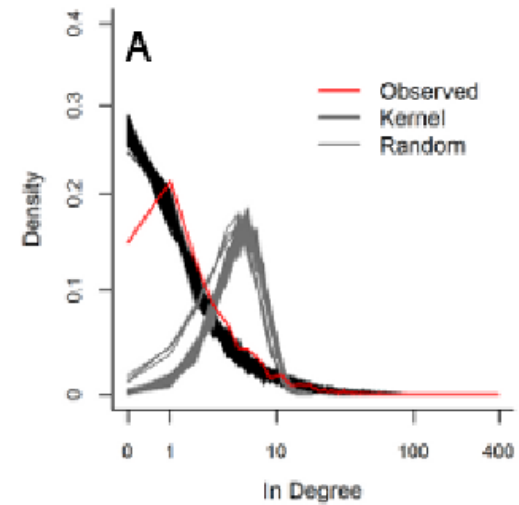
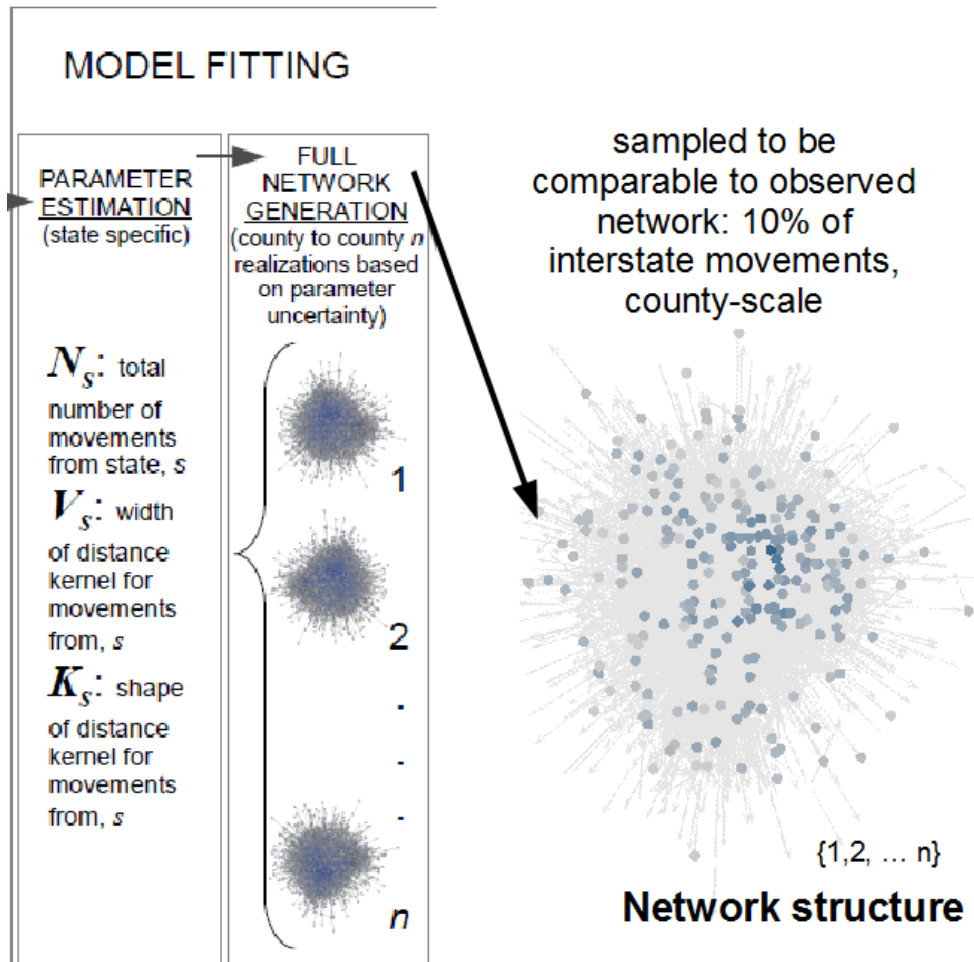


U.S. Animal Movement Model

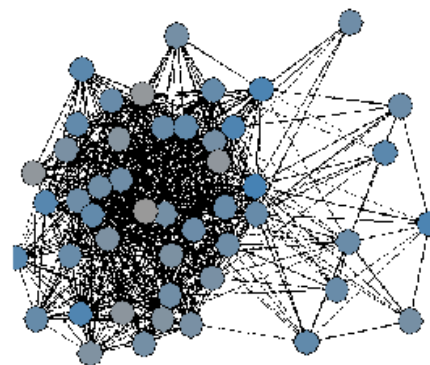
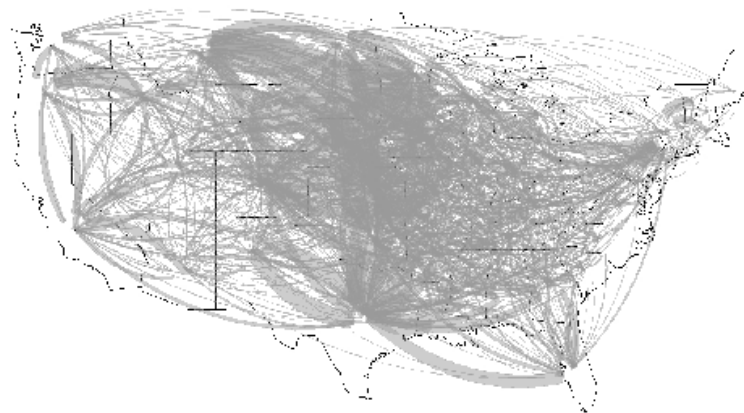
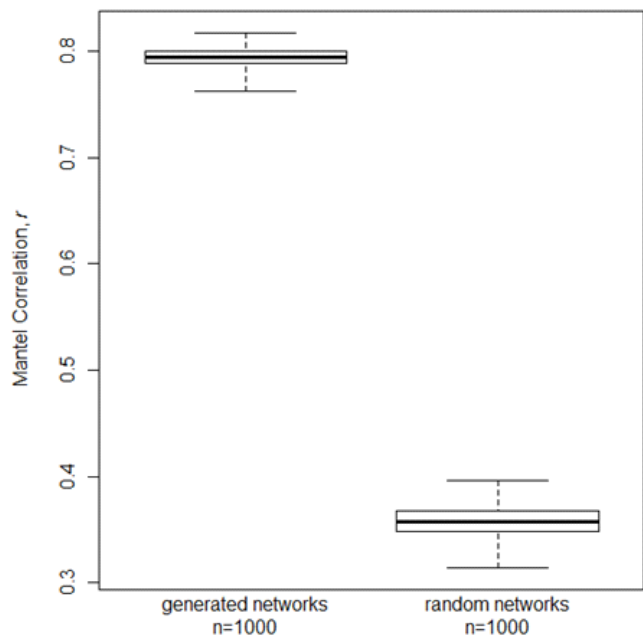


Data = state of origin and distances

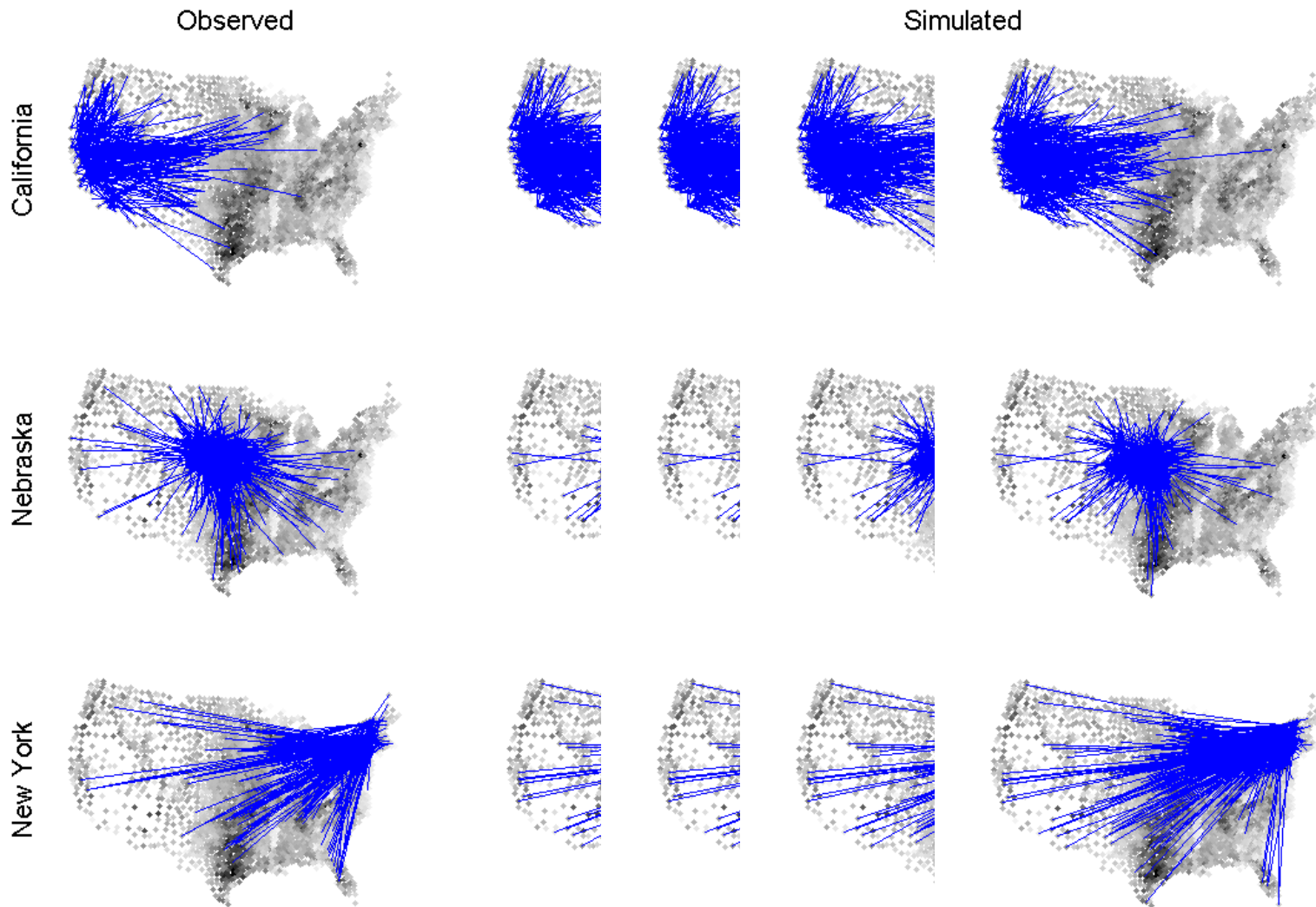
Validating kernel predicted movements



Predictions had a high correlation to the **identity** and **volume** of links geographically



Model Movements With Uncertainty



- One year of data
 - Collected and analyzing 2 additional years
- Intrastate Validation
 - NAHMS data
 - Formal expert elicitation
 - Brand inspection
- Overdispersion
- Seasonality
 - Improvements to model structure
 - Additional years

- Stochastic metapopulation model
 - counties are patches
- Within counties, individual premise is unit of infection
- Susceptible-Exposed-Infectious-Detected-Removed

Two modes of transmission

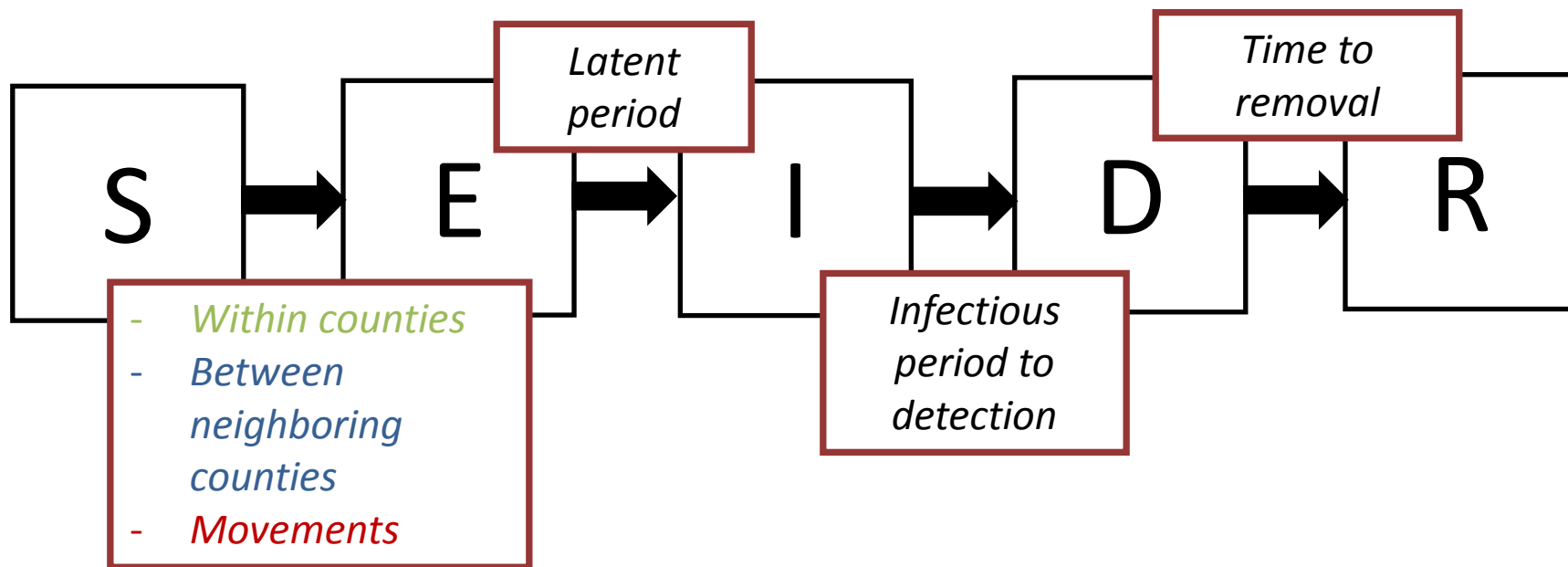
Long range movement based on shipping animals

- Parameters estimated from ICVI data using USAMM
- Uncertainty in movement incorporated from USAMM

Local, non-movement contacts from aerosol, direct or fomite transmission

- Density and distance dependent transmission
- Spatially localized within and between neighboring counties
- Used parameterization based on 2001 FMD outbreak in UK
- Applied sensitivity analysis to 5 parameters to explore impact on outputs
- Additional NASS data on US premises density and size distribution

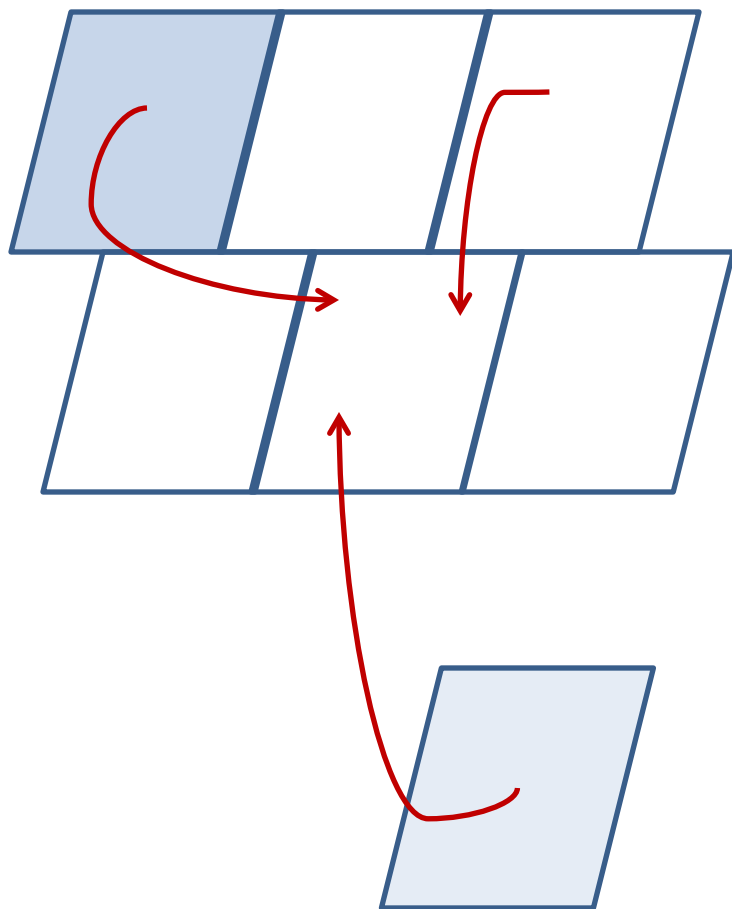
Event-Based Real-time Model



Basic Equation:

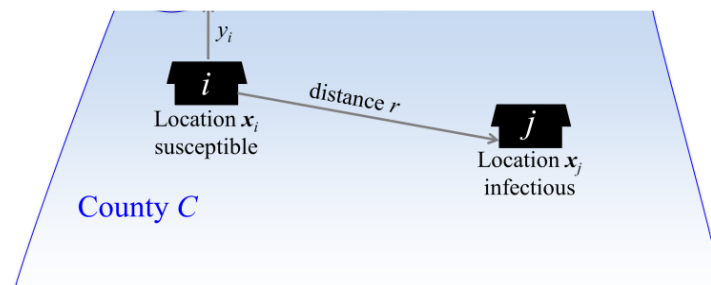
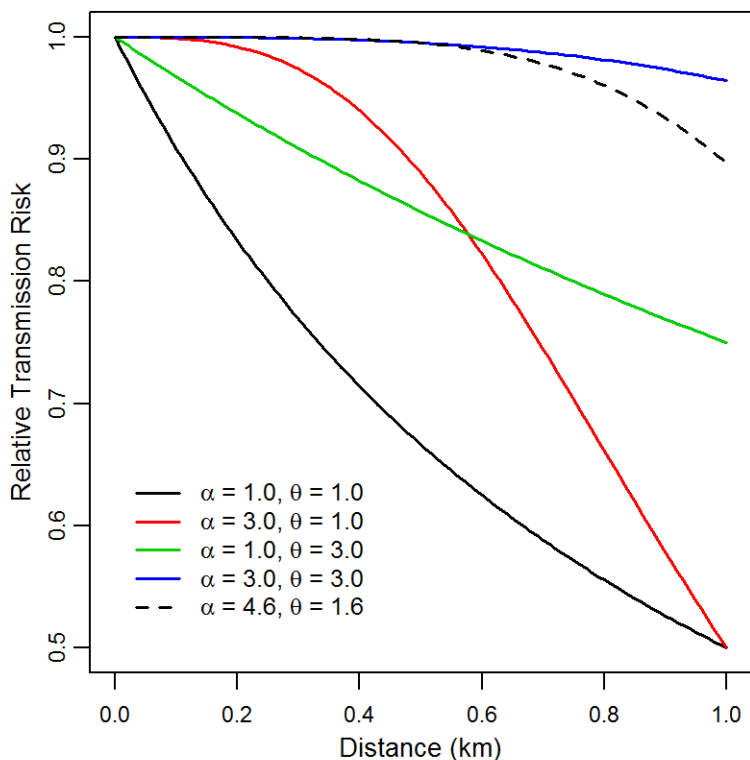
$$W_C \frac{S_C I_C}{F_C} + \sum_C B_{C,C_1} \frac{S_C I_{C_1}}{F_{C_1}} + \sum_{C_2} M_{C,C_2} \frac{S_C I_{C_2}}{F_{C_2}}$$

Long Distance Movement Spread

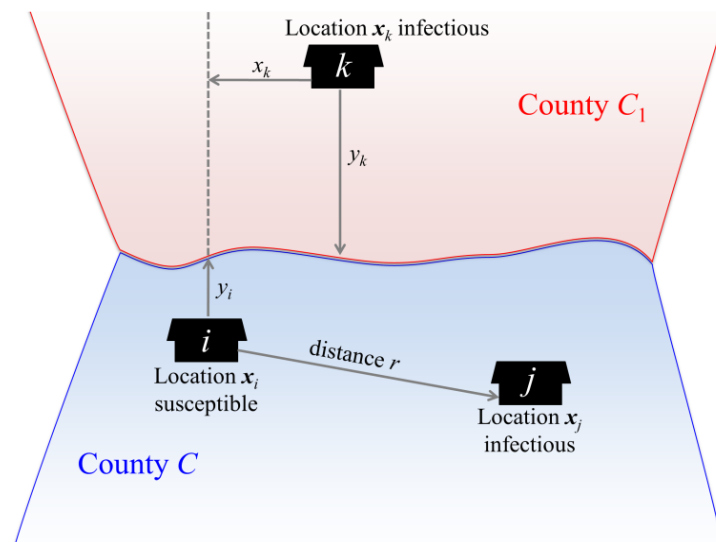
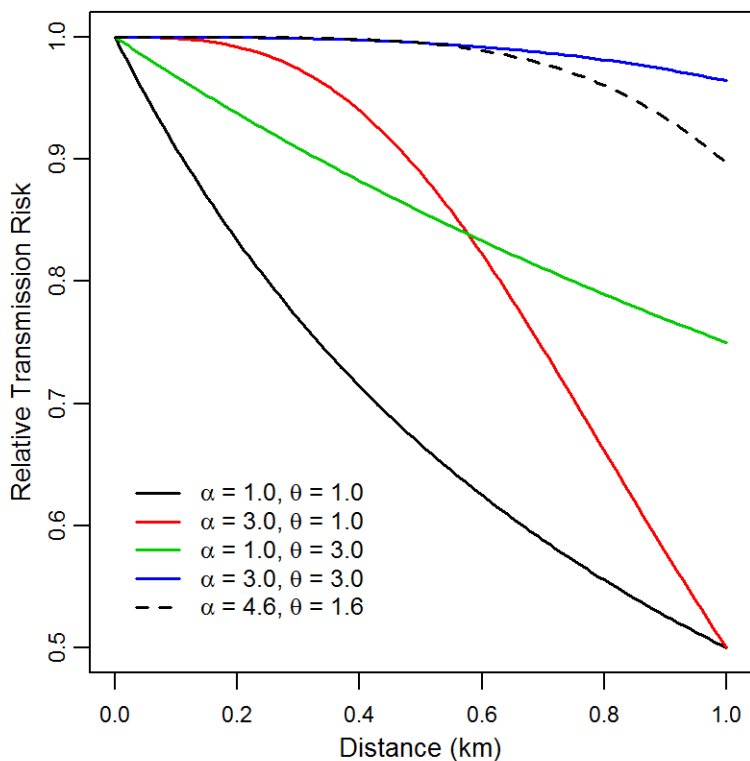


- Daily probability of movement from USAMM
- Probability of I to S premise based on proportion of total premises in S and I classes
- Uses NASS data to determine total premises
- Assumes premises chosen randomly within county

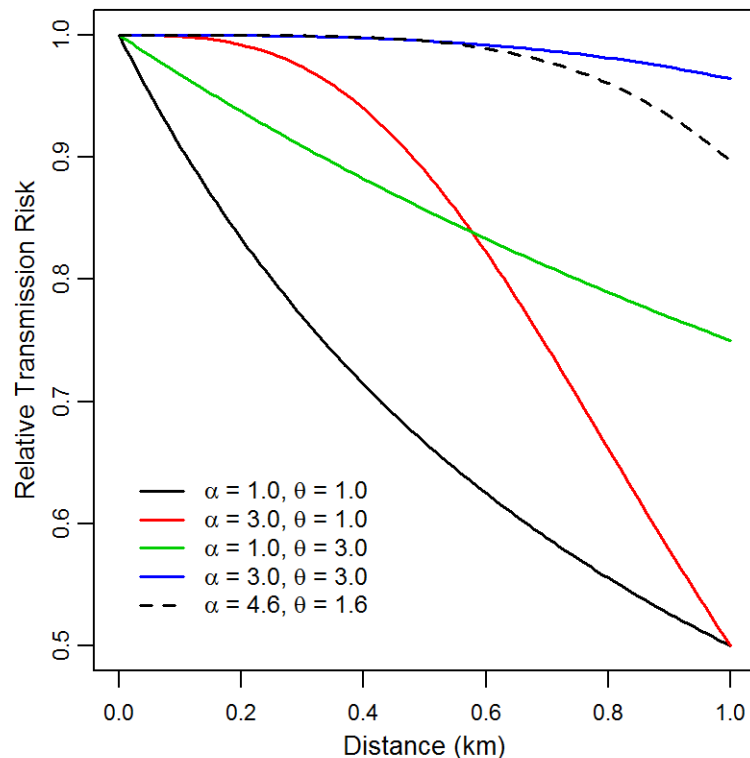
- Probability of I to S contact based on proportion of total premises in I and S categories
- Distance decay of transmission



- Probability of *I* to *S* contact based on proportion of total premises in *I* and *S* categories
- Distance decay of transmission



- Allows transmission parameterization at a national scale
- With local correction for county level characteristics



This is a phenomenological integration of all non-movement mechanisms of spread Including (but not limited to):

- Feed Trucks
- Milk Trucks
- Shared Equipment
- Shared Personnel

*challenging to parameterize



100 simulations of an infection seeded in each county,
Each simulation uses a different realization of USAMM

- Epidemic extent:
 - number of counties infected
- Infection risk:
 - number of times a focal county is infected when infection is seeded in every other county in turn

We investigated the impact of movement restrictions on disease spread

- No control
- County Level Movement Ban
 - all movements from an infected county cease when the first livestock are detected in that county.
- State Level Movement Ban
 - all movements from an infected state cease when the first livestock are detected in that state.

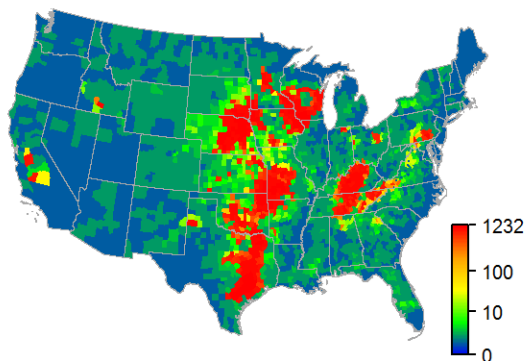
No movement controls

Worst-case

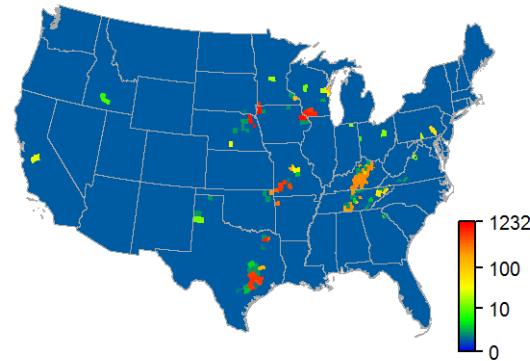
Median

Epidemic extent

A

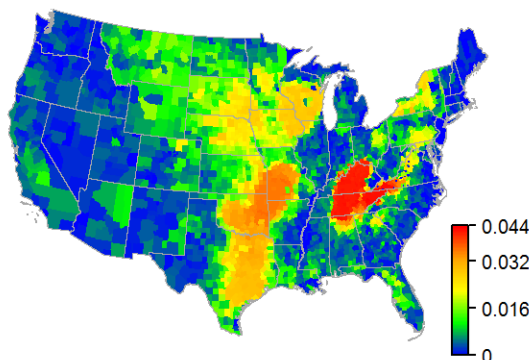


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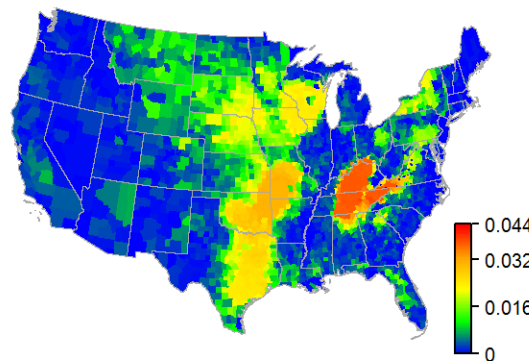


Infection risk

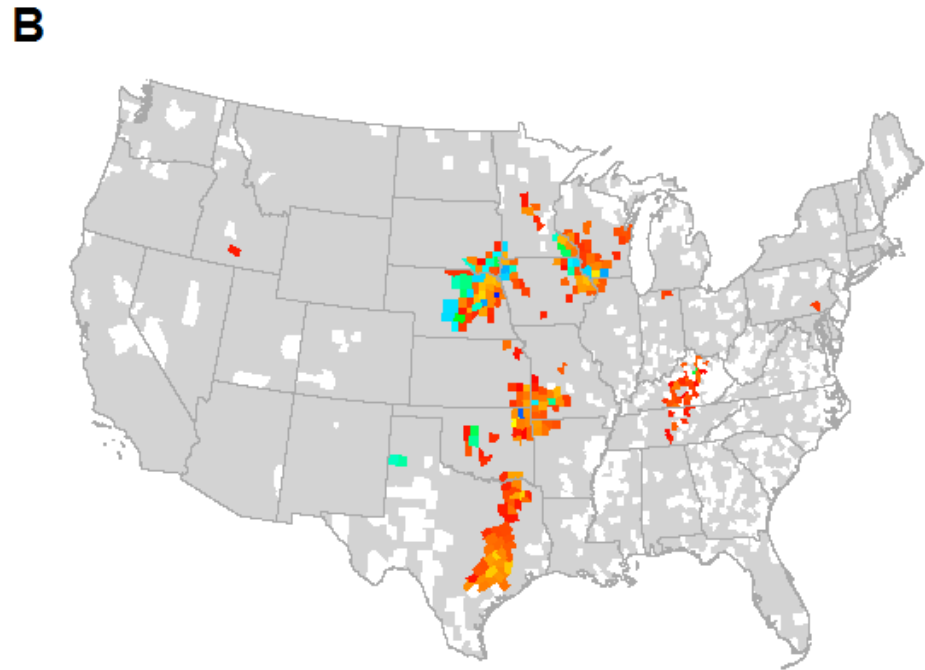
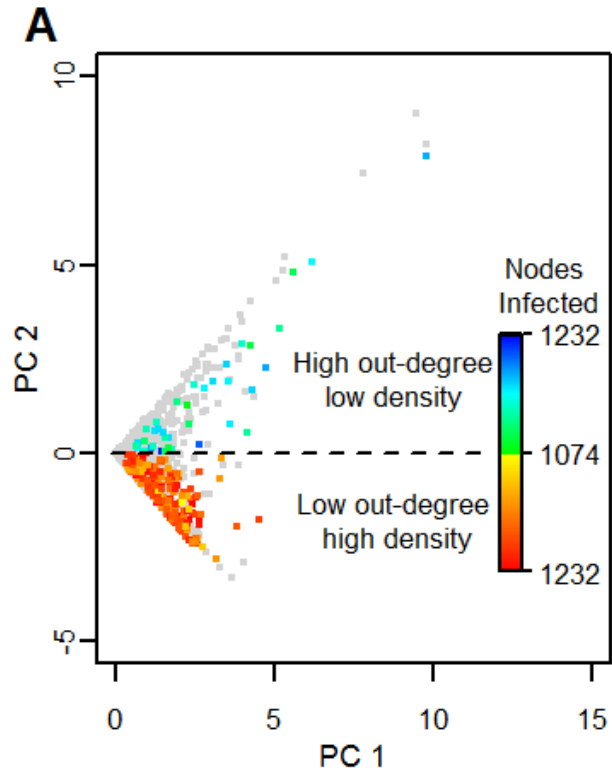
C



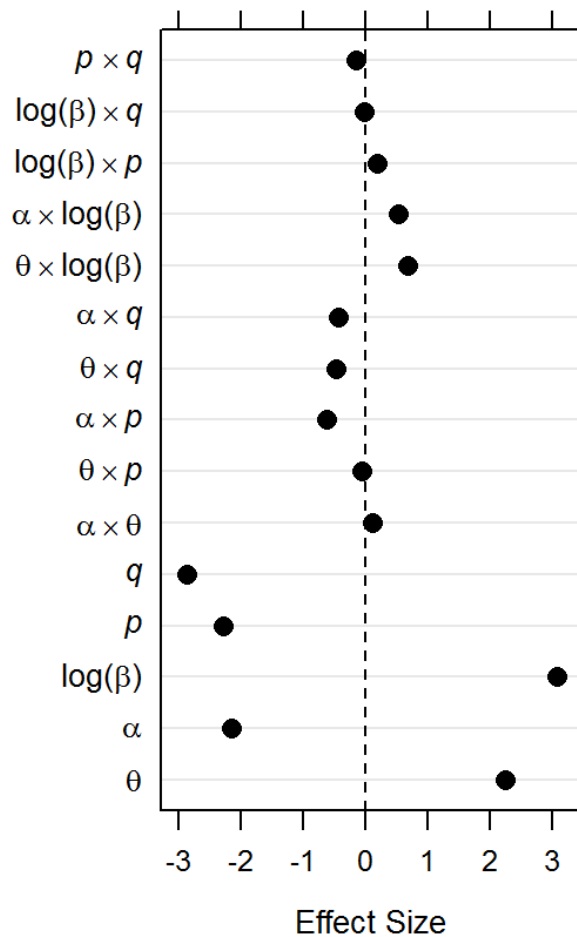
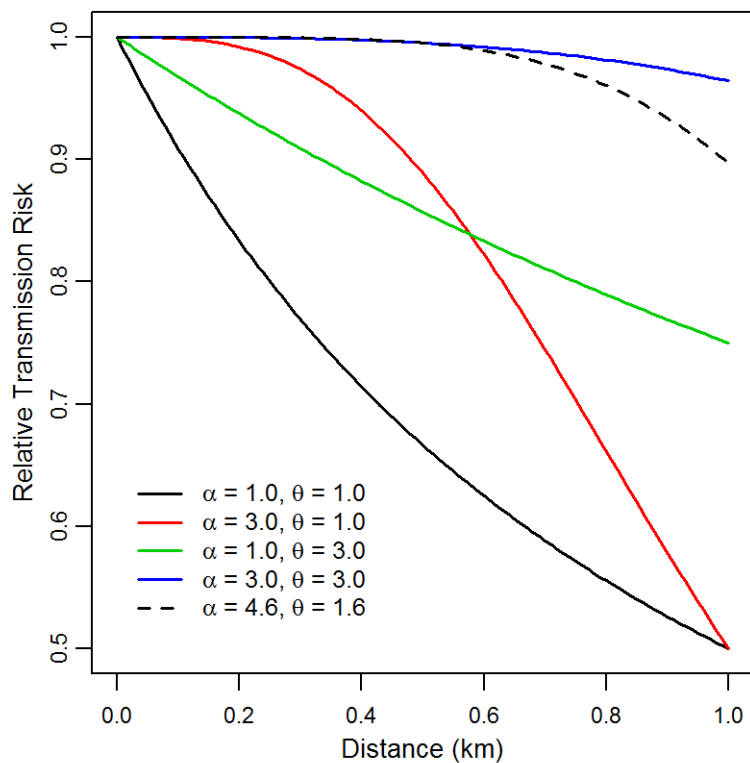
A



Movement *and* Local Spread

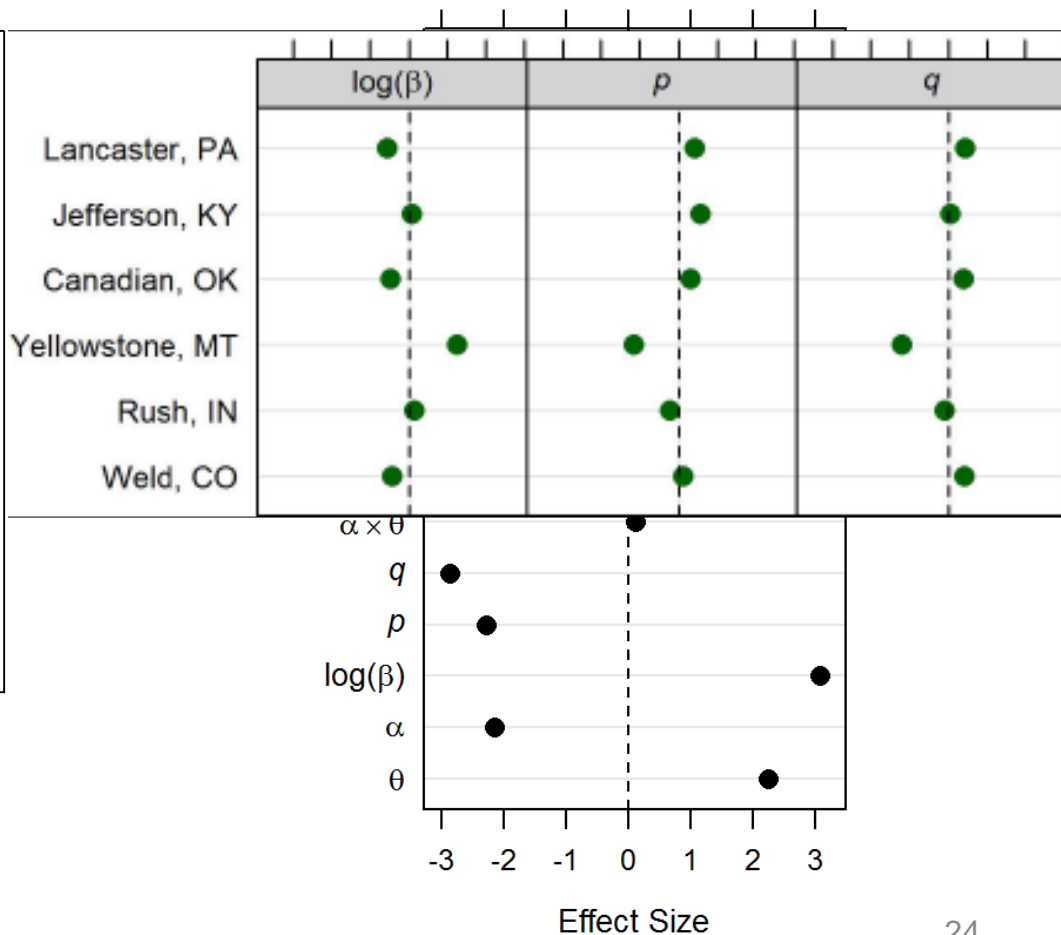
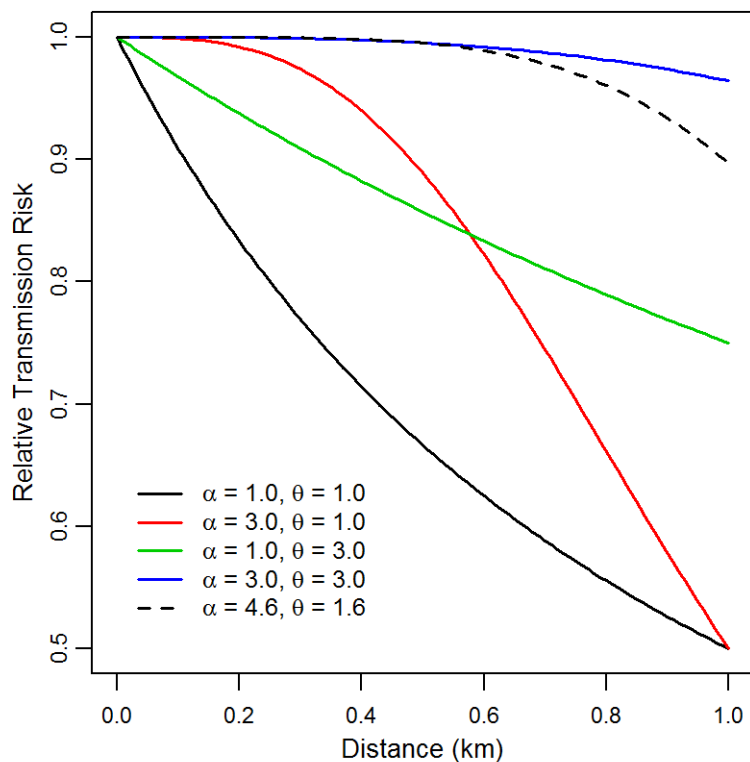


Output is Sensitive to Disease Transmission Parameters



Output is Sensitive to Disease Transmission Parameters

...but does not vary geographically



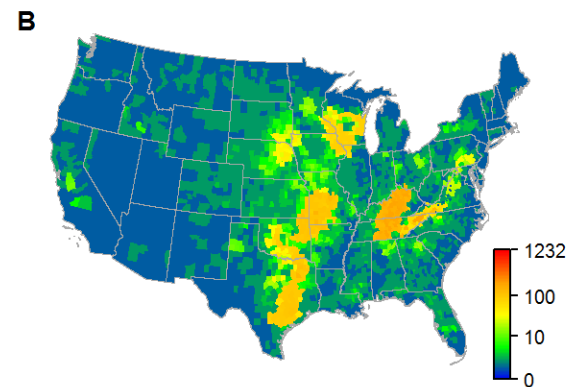
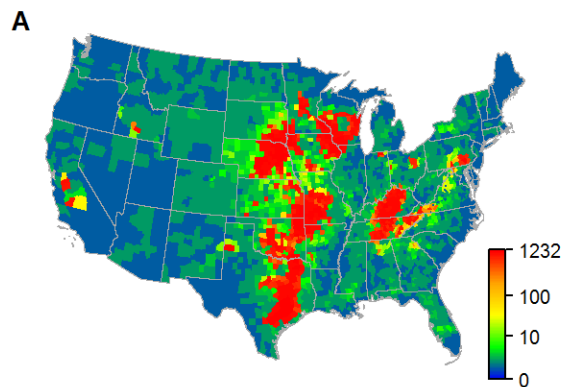
Considering Movement Bans

Worst-case

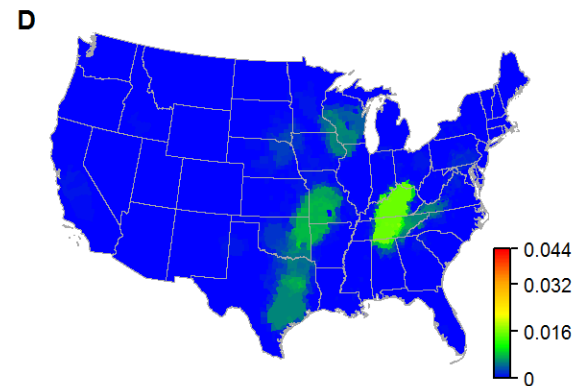
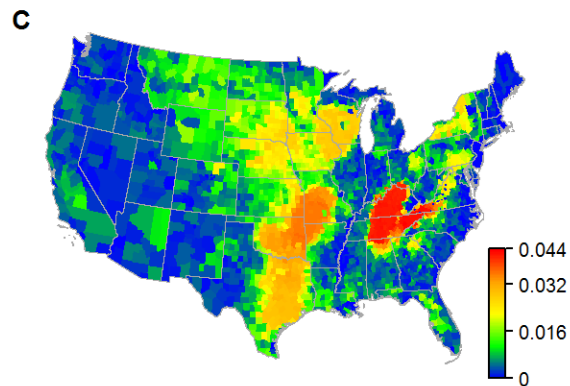
No movement ban

County Movement ban

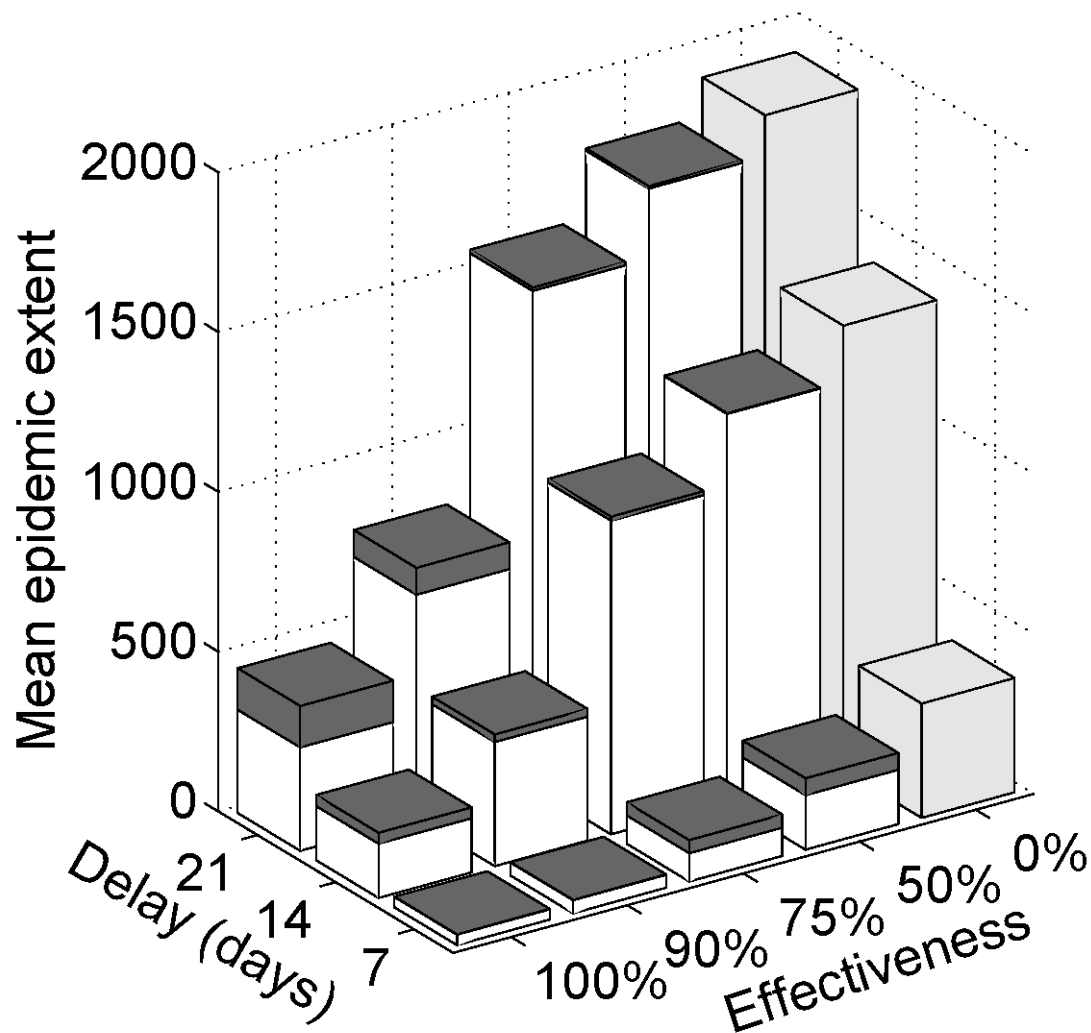
Epidemic extent



Infection risk



Sensitivity Analyses on Disease Control



- Worst-case predictions are for introduction to the Central Plains or Ohio River Valley
 - Up to 1200 counties and 120,000 cattle premises
- Epidemics driven by combination of movement and farm density
- County level movement bans implemented quickly (even if less effectively) are similar to state level movement bans
 - Delay in movement ban implementation suggests effective, state level bans needed

Sensitivity analysis suggests that qualitative geographic results are robust to parameterization

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Sensitivity analysis suggests that qualitative geographic results are robust to parameterization

More data

- Movement Inference from multiple years

Model Developments

- Farm location
- Seasonality and updates to movement components

Application

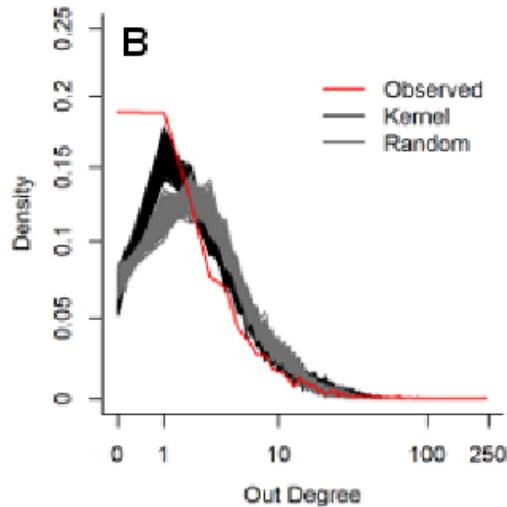
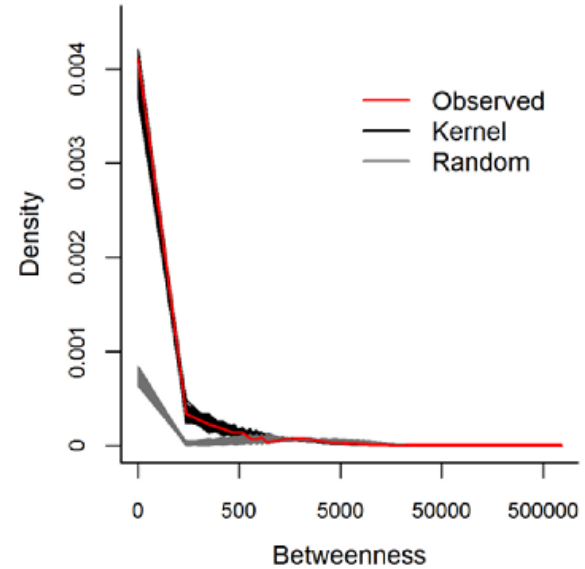
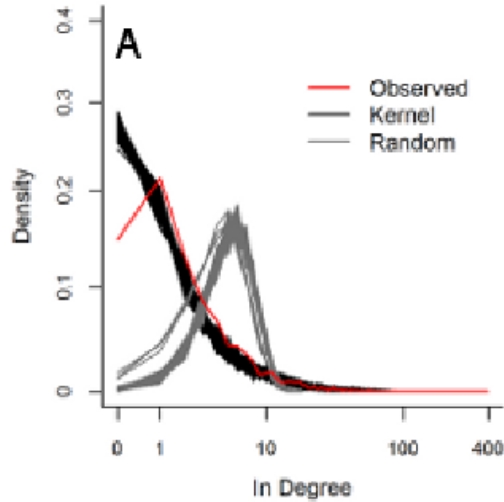
- Vaccination

Acknowledgements

- USDA
- DHS
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 - Matt Keeling, *Warwick University*
 - Michael Buhnerkempe, *UCLA*
 - Jason Lombard, Ryan Miller and Katie Portacci, *USDA CEAH*

Questions?





Network Centrality

- Captures most of distribution
- Missing extreme highly central counties