EVALUATING OPTIMAL CONTROL STRATEGIES FOR FOOT-AND-MOUTH DISEASE WITH THE U.S. DISEASE OUTBREAK SIMULATION

Stefan Sellman[1], Lindsay M. Beck-Johnson[2], Kimberly Tsao[3], Amanda Minter[4], Deedra Murrieta[2], Clayton Hallman[3], Ryan S. Miller[3], Katie Portacci[3], Peter Brommesson[1], Uno Wennergren[1], Tom Lindström[1], Michael J. Tildesley[4] & Colleen T. Webb[2]

[1] Linköping University

[2] Colorado State University

[3] USDA-APHIS-VS-CEAH

[4] University of Warwick

THE U.S. DISEASE OUTBREAK SIMULATION - USDOS

- National-scale (i.e. continental-scale) premises-level simulation tool for modeling infectious disease within the United States cattle population.

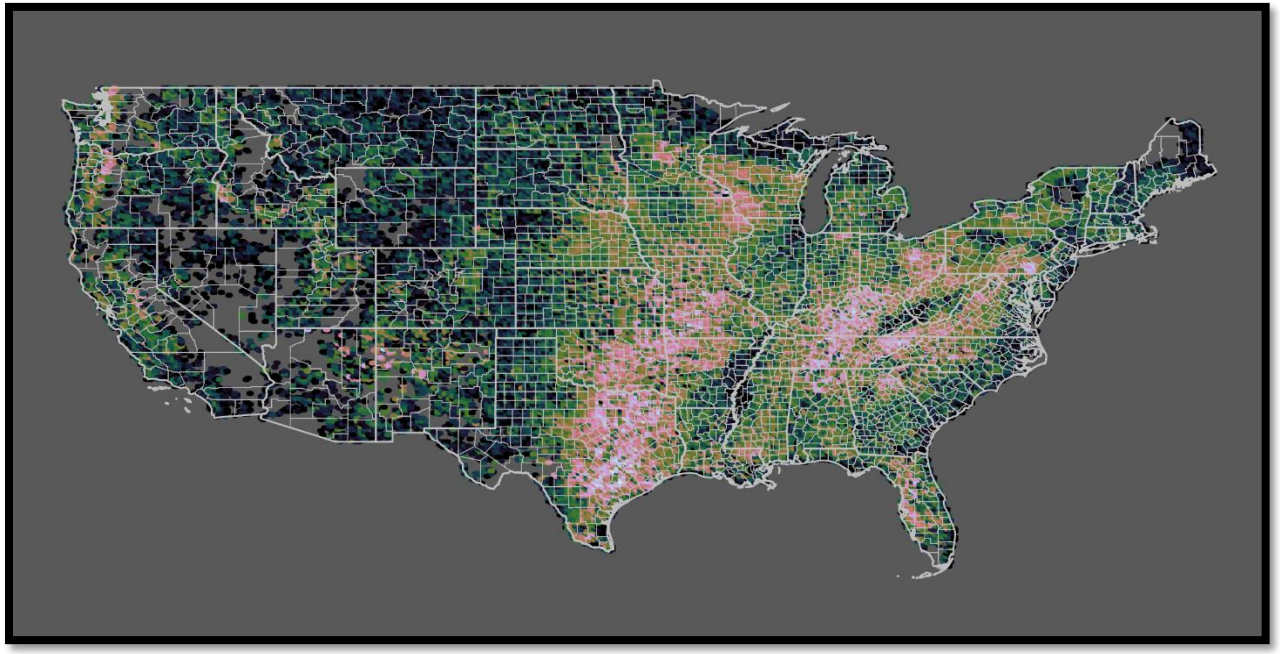
- Kernel based local spread + long-distance transmission via a stochastic process to generate shipments.

U.S. CATTLE PREMISES DATA

- ~815,000 cattle premises with over 100 million beef and dairy animals.
  Largest premises (feedlots) >100,000 animals.

- Spatial data aggregated at county level for different size classes (NASS).

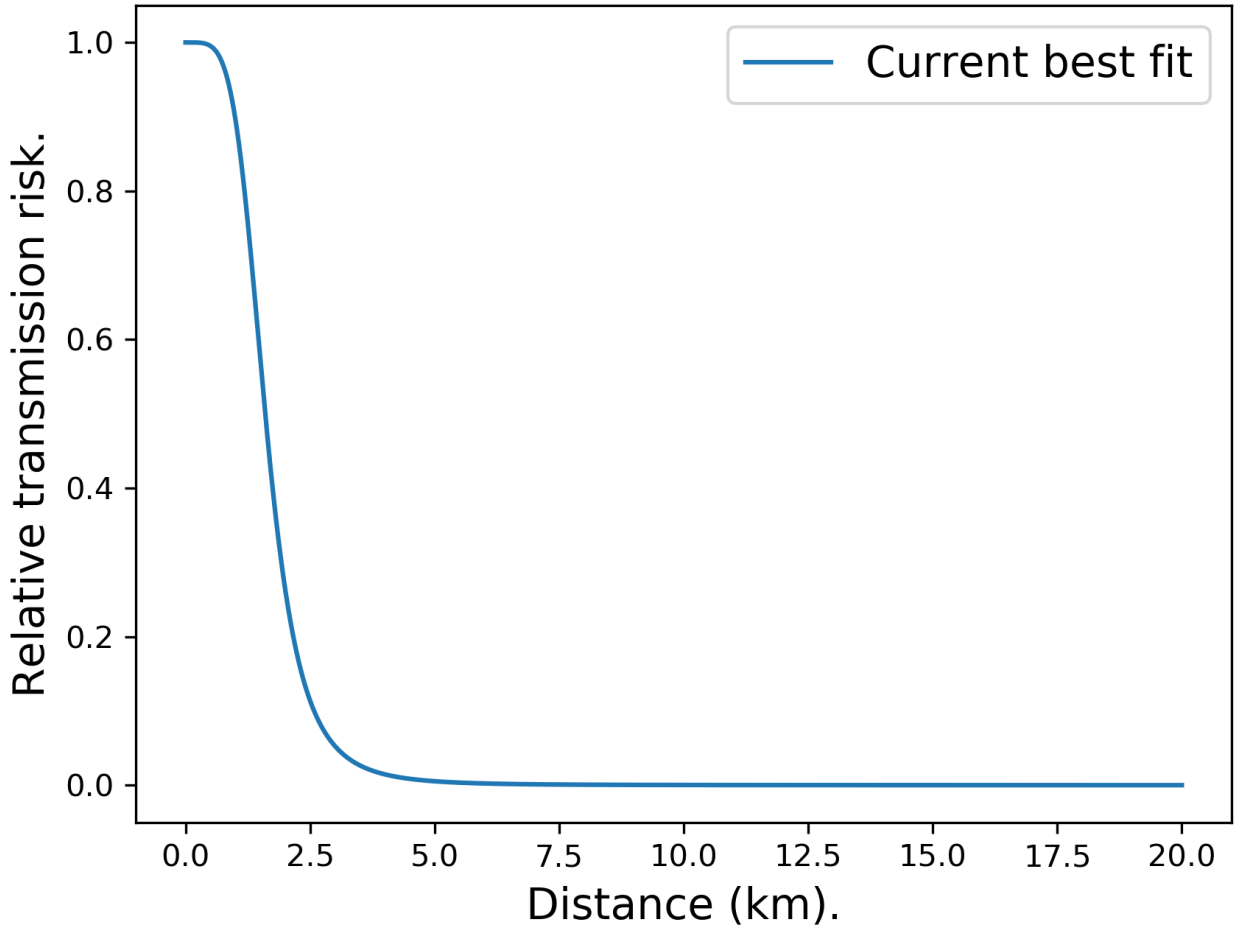
- Precise locations need to be simulated using the Farm Location and Agricultural Production Simulator (FLAPS).



- FLAPS: environmental + geographical + anthropogenic predictors -> probability surface for premises occurrence.
  - NASS information to get the county-level size distributions right.
  - More information about FLAPS: Burdett et al. 2015

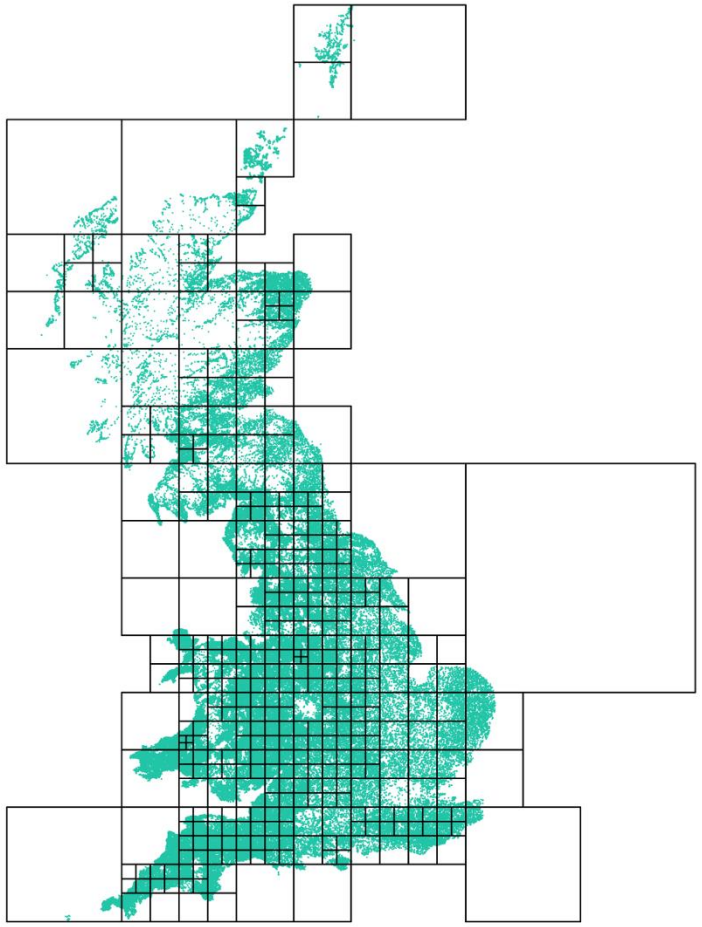
USDOS - LOCAL TRANSMISSION

- Local transmission encapsulates any transmission that is not via shipment.
  - $\lambda_{ij} = T_i S_j K(d_{ij})$
  - $K(d_{ij}) = \frac{\alpha}{1+\left(\frac{d_{ij}}{\beta}\right)^{\gamma}}$
- Kernel parameters fitted to the 2001 UK FMD outbreak data.
  - Current best fit: transmissibility and susceptibility scales linearly with number of animals on premises.
- Model parameters
  - Exposure to infectiousness, 5 days.
  - Infectiousness to immunity, 7 days (in event of no control).



USDOS - LOCAL TRANSMISSION CONT.

- Evaluation of local transmission between all possible infected-susceptible premises pairs is very computationally intensive and requires specialized algorithms.
- Our approach: grid the landscape and evaluate in a hierarchical manner first between grids and only if necessary between premises.
- Around 500 times faster than the naïve approach.
- Sellman et al. 2018 for details.



USDOS - SHIPMENT TRANSMISSION

- Cattle shipments generated continuously throughout the simulation.
- Based on premises-size dependent shipment rates.
- Rate governed by kernel-based distance dependence and county-level infrastructure covariates.
- Parameters estimated using the separate model USAMM (U.S. Animal Movement Model, Lindström et al. 2013).
- Challenging because the best available shipment data is a 10% sample of shipments crossing state borders.

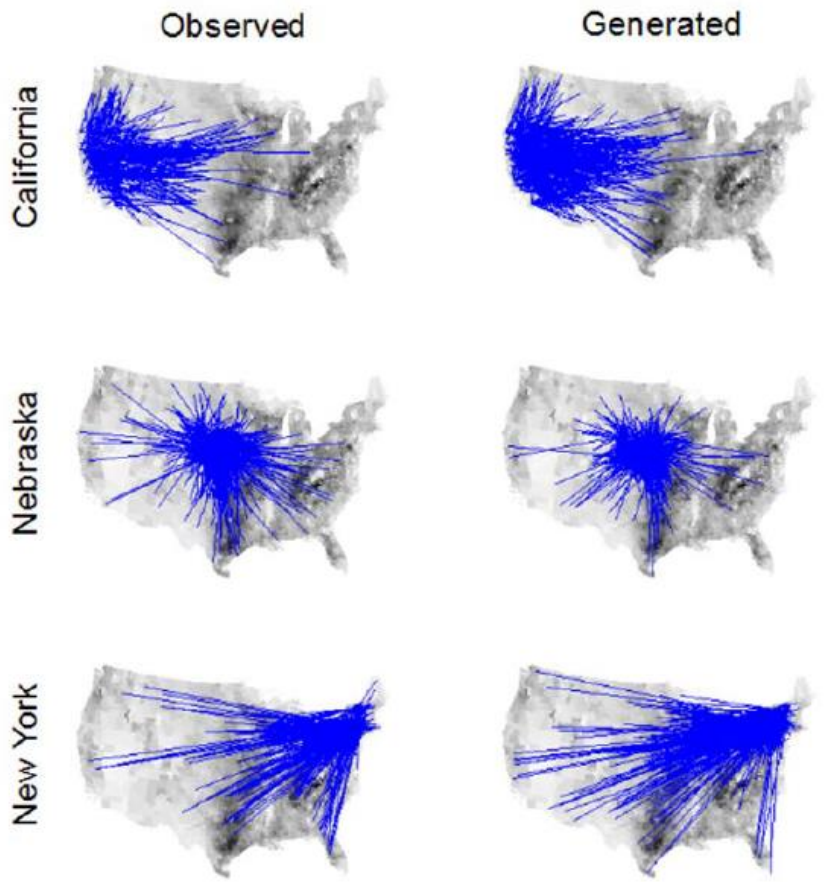


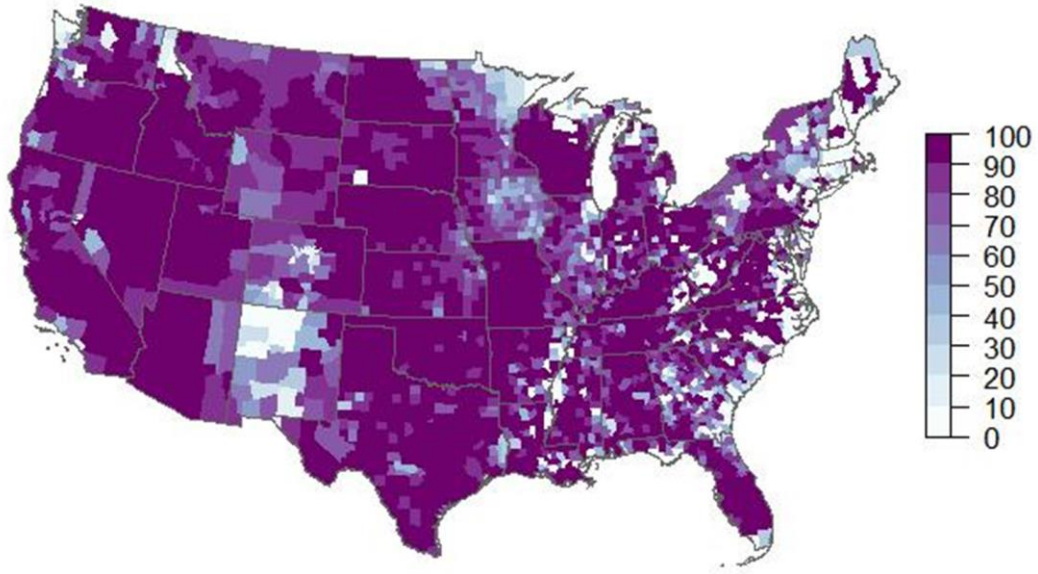
Figure: Lindström et al. 2013

IMPORTANCE OF SHIPMENTS

Simulations

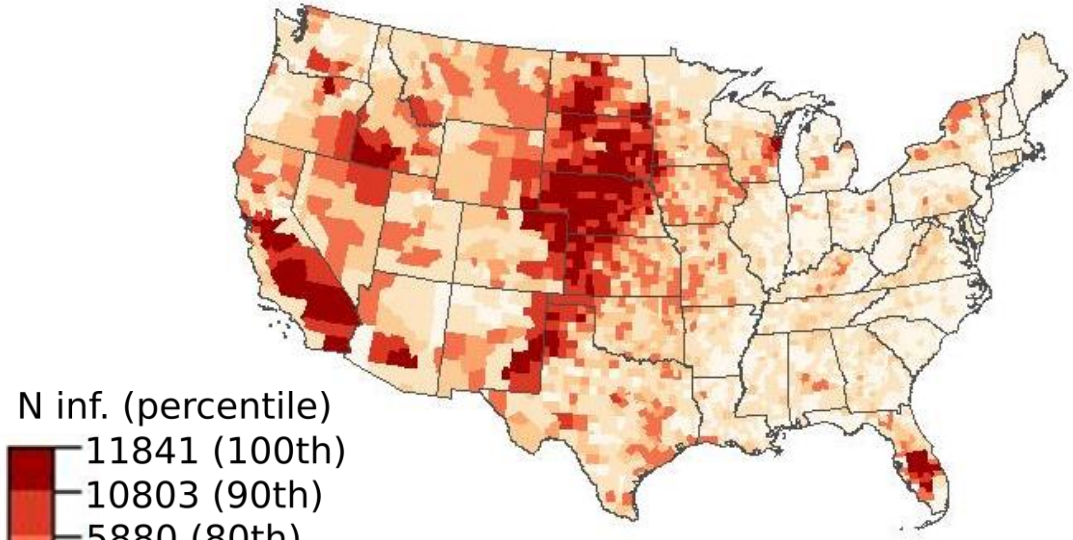
- Random farms in each county seeded and simulation run until outbreak dies out.
- On average roughly 0.3 shipments / year and premises.
- Shipments are relatively rare, but have a large impact on outbreak dynamics.

Percent of direct transmission from local spread.

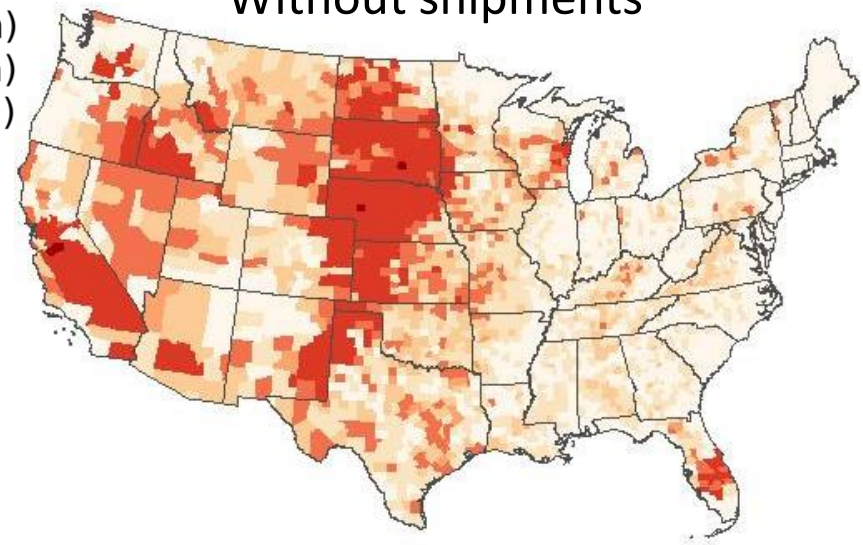


Total number of infected farms, given that the outbreak begins in this county.

With shipments



Without shipments



CONTROL STRATEGIES

- Movement restrictions, depopulation, vaccination, modeling of dangerous contacts.
- USDOS allows for constraints in daily animal volumes that can be vaccinated or depopulated.
- Control scenarios parameterized with input from USDA subject matter experts.

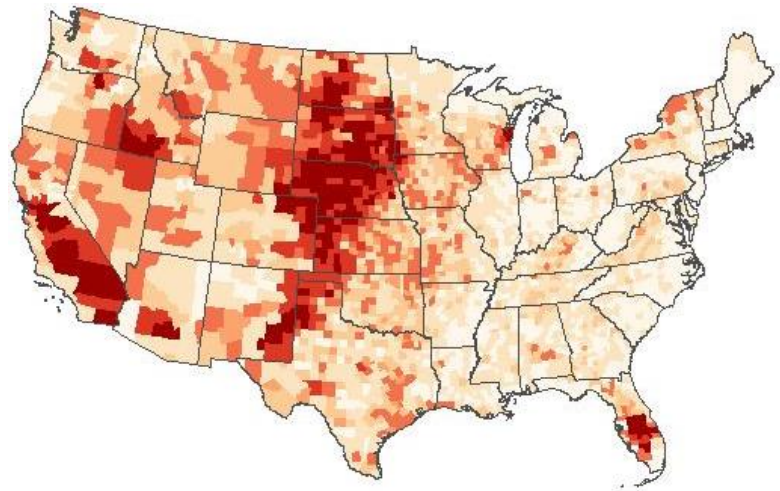
Scenarios:

Depopulation of both infected farms and dangerous contacts together with state-level movement restrictions.

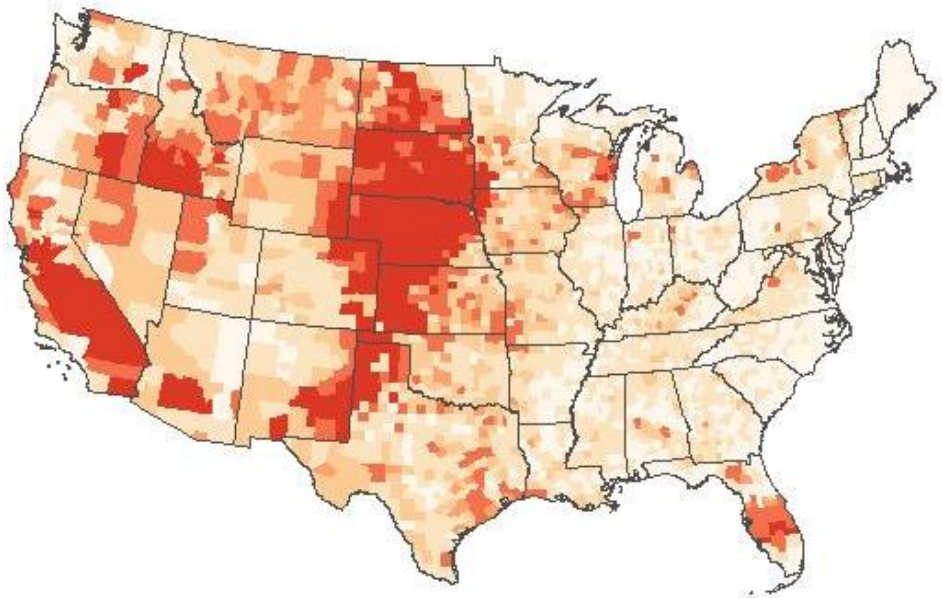
Depopulation of infected farms and vaccination of dangerous contacts together with state-level movement restrictions.

Total number of infected farms, given that the outbreak begins in this county.

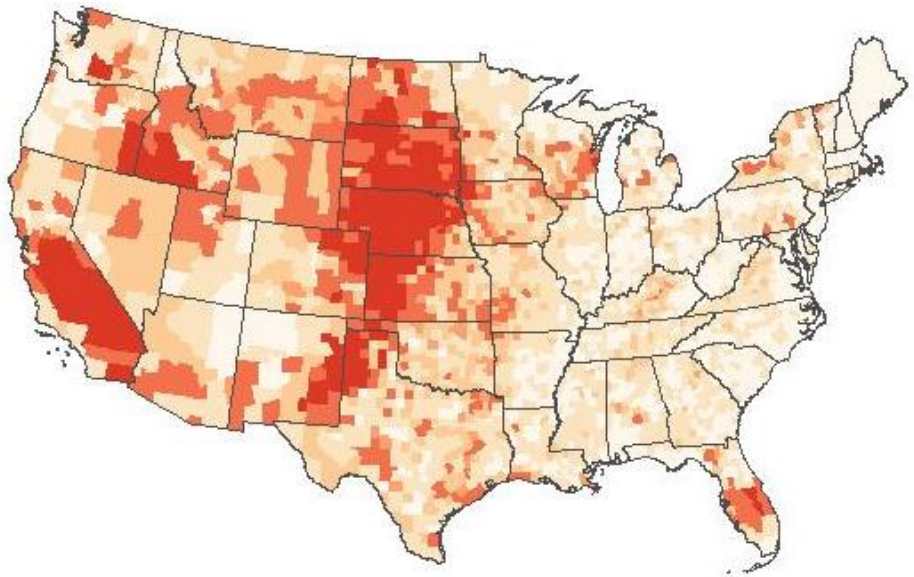
No Control



Culling Strategy



Vaccination Strategy



CONCLUSIONS – CONTROL STRATEGIES & SHIPMENTS

- USDOS allows us to efficiently simulate outbreaks and evaluate control strategies
  - In a very large cattle population.
  - Without exact locations of premises.
  - With limited information about shipments.
- Control can shift the predicted national scale patterns.
- Shipments are uncommon but has the potential to greatly increase outbreak size

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The Findings and Conclusions in This Preliminary Presentation Have Not Been Formally Disseminated by the U. S. Department of Agriculture and Should Not Be Construed to Represent Any Agency Determination or Policy.

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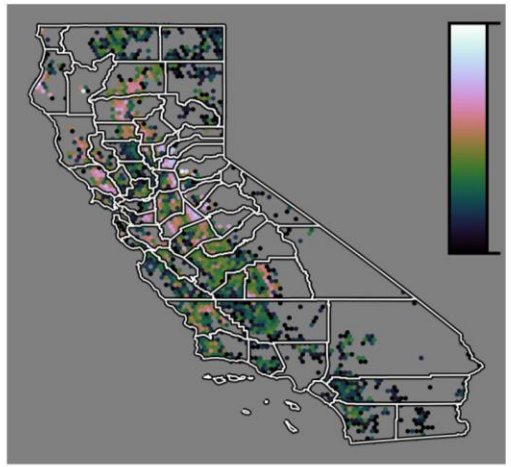
IMPORTANCE OF SPATIAL CLUSTERING

(work in progress)

- When spatial distributions of premises are unavailable, assumptions need to be made.

- Sophisticated approach such as FLAPS or simpler approach such as a uniformly random distribution?
  - High local transmission within cluster.
  - Less spread between clusters?

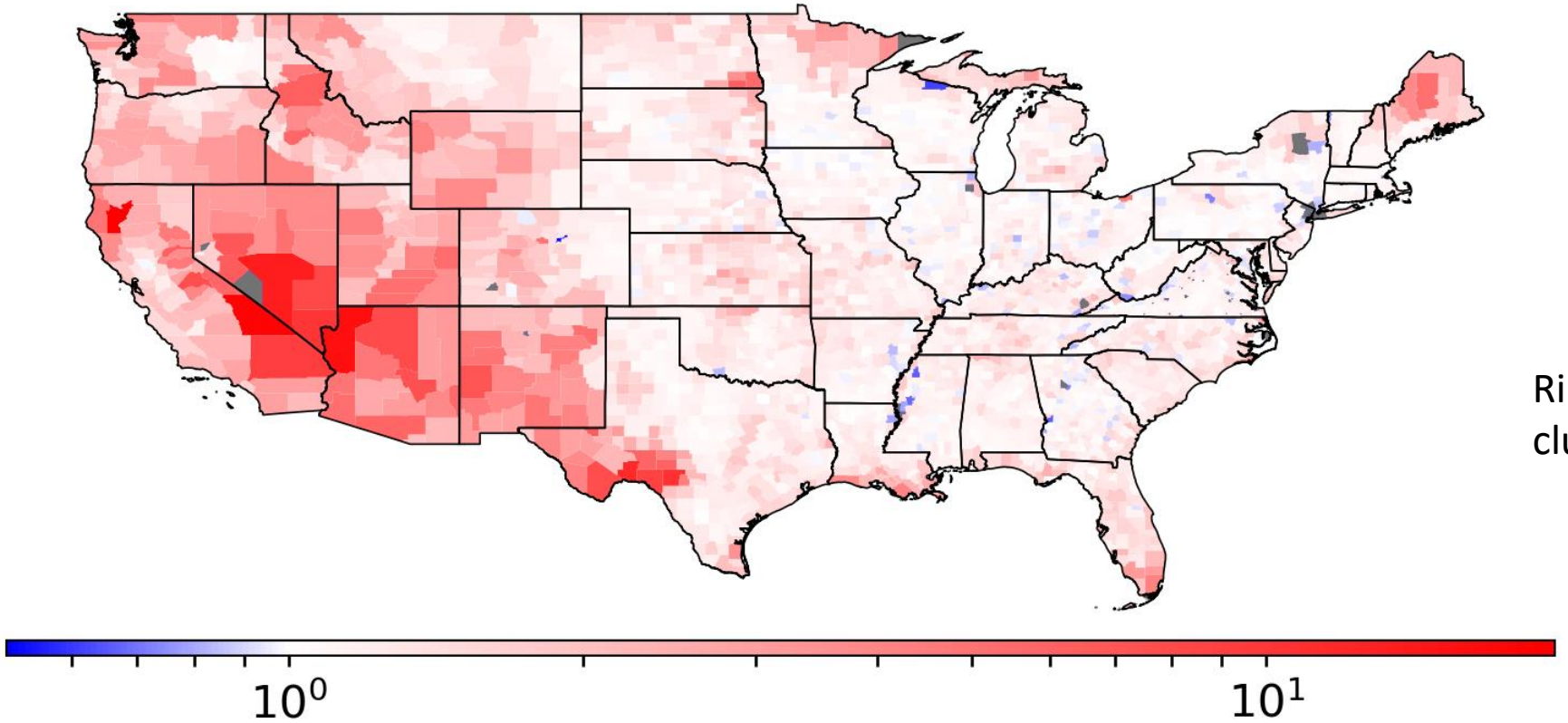
- We analyzed the difference between transmission through local spread using FLAPS or uniform within each county.



FLAPS

Uniformly random within counties

COUNTY LEVEL CLUSTERING OF CATTLE PREMISES



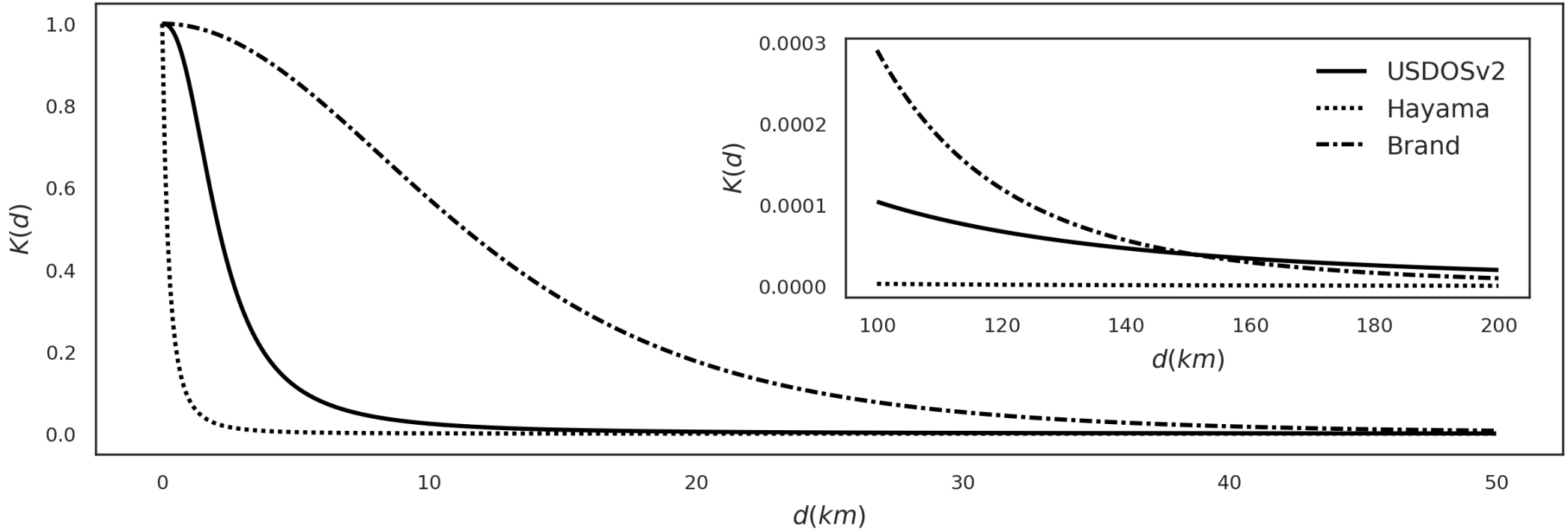
Proportional difference in clustering (Ripley's K) measured at the county-level between FLAPS landscapes and randomized ones (K_{FLAPS} / K_{RAND}).

Ripley's K – a measure of spatial clustering at a specific radius, r.

More **RED** = More clustered in FLAPS

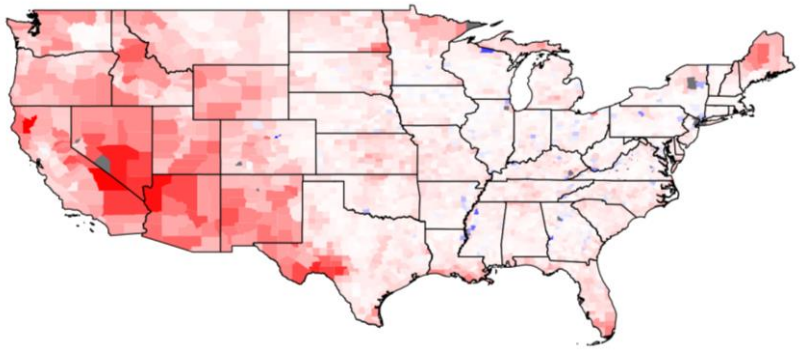
SPATIAL CLUSTERING CONT.

- Simulations and R0.
- USDOS-kernel plus two other published kernels for variation.



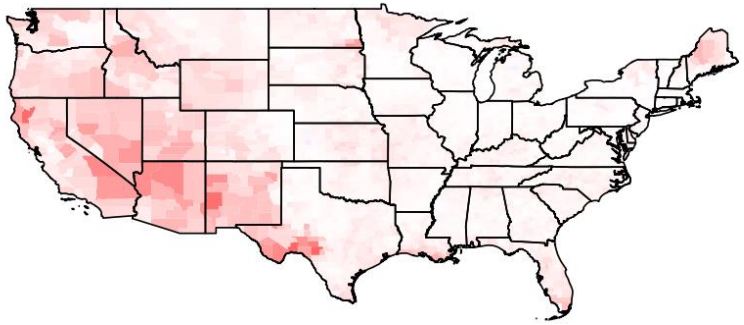
Kernels from Hayama et al. 2015; Brand et al. 2015.

R0 RESULTS

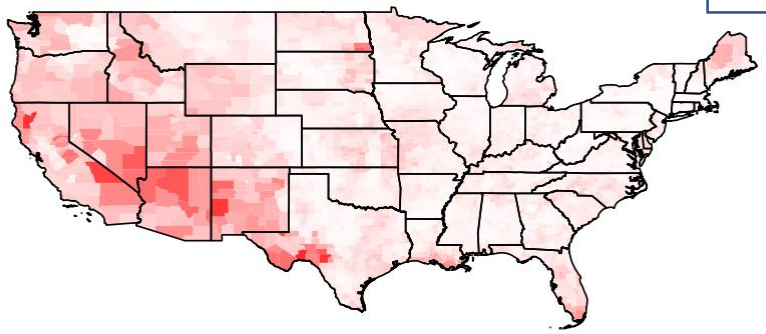


Difference in clustering for reference.

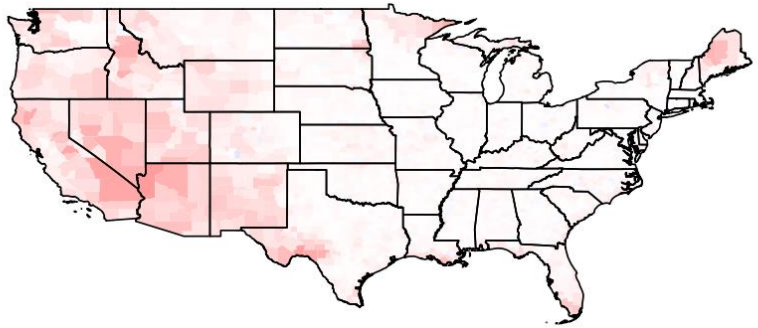
USDOS

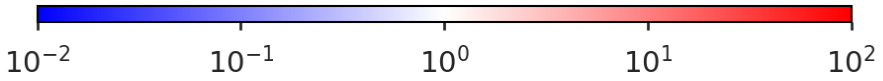


Hayama



Brand 5





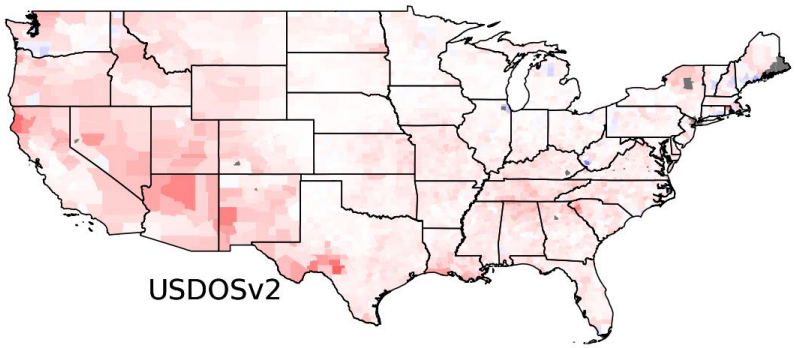
Response variable: county geometric mean of premises-level R0

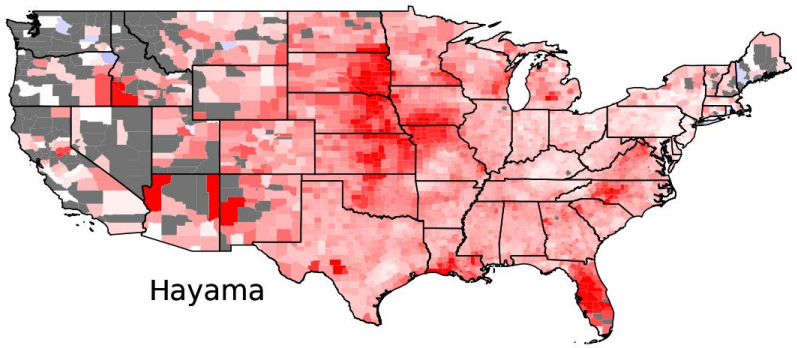
Proportional difference in response variable between FLAPS and randomized landscapes.

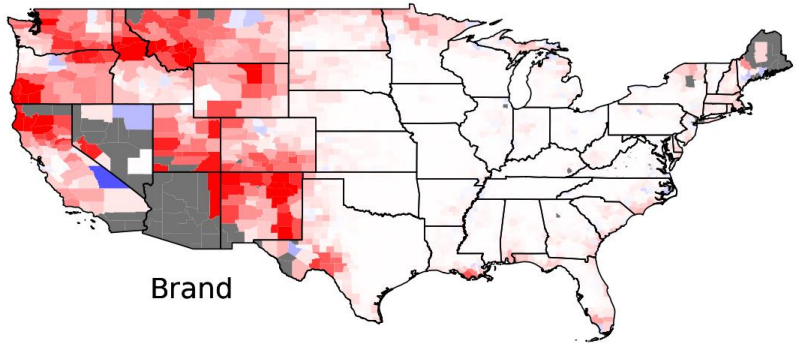
RED = higher R0 with FLAPS.

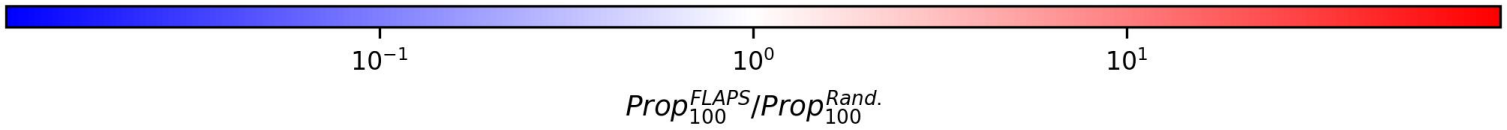
BLUE = higher R0 with randomized landscapes.

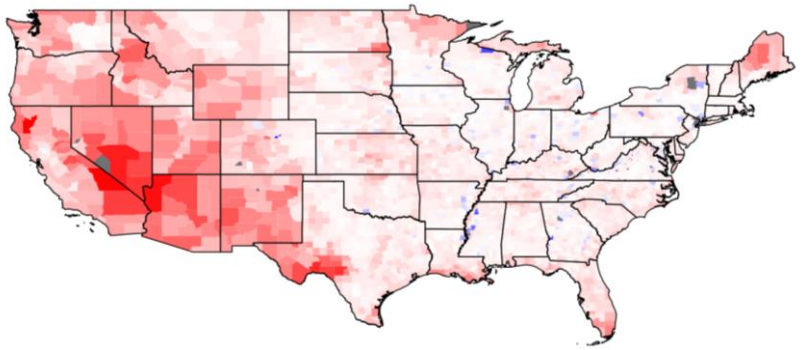
SIMULATION RESULTS











Difference in clustering for reference.

Response variable: proportion of 100 seeding attempts per county leading to outbreaks with at least 1000 total infected premises.

Proportional difference in response variable between FLAPS and randomized landscapes.

RED = more big outbreaks with FLAPS.

BLUE = more big outbreaks with randomized landscapes.

GRAY = no outbreaks reaching 1000 infected premises.

CONCLUSIONS – CLUSTERING STUDY

- Using randomized spatial distributions of premises can lead to severe underprediction of outbreak sizes compared to clustered populations.
  - Both measured using R0 and simulations.
  - Highlights the importance and usefulness of a method such as FLAPS for countries or areas where information on spatial distributions is unavailable.