Integrating Travel and Epidemic Models for Vector Borne Disease Surveillance

presented to

7th International Conference on Innovations in Travel Modeling

presented by

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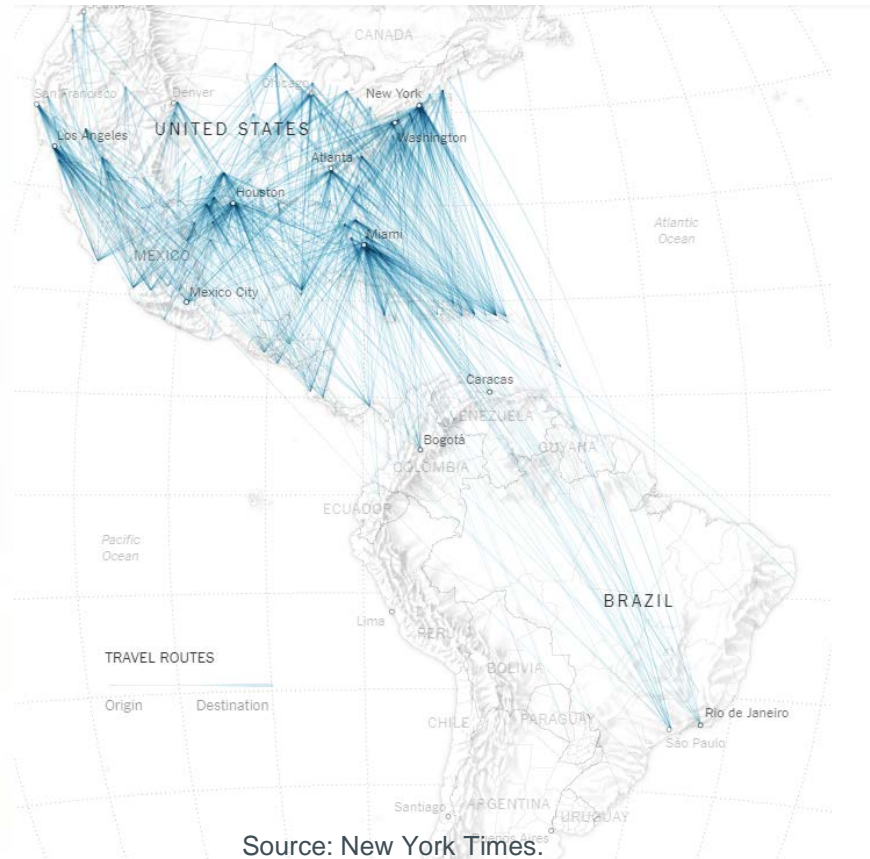
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Think Forward

June 27, 2018

Agenda

→ Objectives and Motivation

→ Methodology and Data

→ Results

→ Summary and Next Steps

Objectives and Motivation

- Air Travel Implications

- Risk maps of local transmission

- FAA data good but inadequate

- Epidemic model limitations

- Link travel models with metapopulation epidemic models to develop risk maps

Source: New York Times.
https://www.nytimes.com/interactive/2016/02/06/science/air-travel-from-countries-affected-by-zika.html

Data

➤ Vector borne disease outbreaks

Disease	Year	Travel Imported	Local	Source-of-data
Chikungunya	2014	475	12	CDC
Dengue	2009-10	N/A	66	FDH
Dengue	2013	70	28	FDH
Zika	2016	1065	274	FDH

➤ Air Travel within Florida

Origin County	Destination Airport	Destination Airport Code	Percent of Passengers from Origin	Number of Passengers (Leakage)	Destination Airport Total # of Passengers
Duval	Orlando	MCO	0.9	173,576	19,286,291
Duval	Daytona	DAB	0.6	1,888	314,700
Alachua	Jacksonville	JAX	2.3	63,214	2,748,451
Leon	Panama City	ECP	1.4	6,195	442,534

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- Steady state between zones for Humans and Vectors
  - » Two zones – Puerto Rico & FL Counties

- The model considers the following:
  - » Number of people in each zone
  - » Estimation number of vectors in those zones
  - » The rate of people movement between two zones

- Find the number of infected humans/vectors for each day
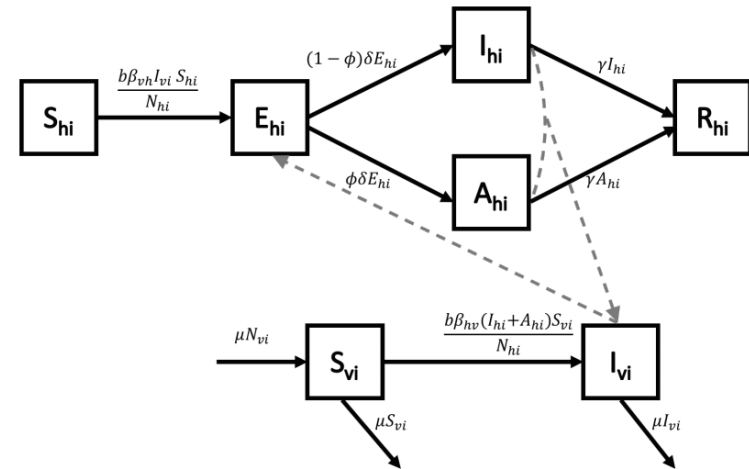
State	→	Variable Description
S_{hi}	→	Susceptible Humans
E_{hi}	→	Exposed Humans
I_{hi}	→	Symptomatic Humans
A_{hi}	→	Asymptomatic Humans
R_{hi}	→	Recovered Humans
S_{vi}	→	Susceptible Vectors
I_{vi}	→	Infected Vectors

Diagram labels:

$$\frac{b\beta_{vh}I_{vi}S_{hi}}{N_{hi}}$$

$(1-\phi)\delta E_{hi}$

$\phi\delta E_{hi}$

γI_{hi}

γA_{hi}

μN_{vi}

$$\frac{b\beta_{hv}(I_{hi}+A_{hi})S_{vi}}{N_{hi}}$$

μS_{vi}

μI_{vi}

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Used parameters

Parameter	Description	Value	Source
b	Biting rate	0.5 per day	Andraud, Hens, Marais, and Beutels (2012)
β_{hv}	Human to vector infection probability	0.5 per day	Chikaki & Ishikawa (2009)
β_{vh}	Vector to human infection probability	0.4 per day	Andraud et al. (2012)
$1/\delta$	Intrinsic Incubation period	5 days	Bearcroft (1956); Kucharski, 2016
γ	Recovery rate	0.14 or 0.25 per day	Gao et al. (2016); Majumder et al., 2016
ϕ	Proportion of asymptomatic infections	0.18	Gao et al. (2016);

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Transportation Models

➜ **Gravity Model**

$$T = \theta \frac{n_i^{\alpha} n_j^{\beta}}{d^{\gamma}}$$

➜ **Radiation Model***

$$\langle T_{ij} \rangle = T_i \frac{m_i n_j}{(m_i + s_{ij})(m_i + n_j + s_{ij})}$$

➜ **Destination Choice Model**

$$U_i = \alpha * (Travel\ time) + \beta * (Waiting\ time\ airport) + \gamma * (Flight\ time) + \delta * (Flight\ price)$$

$$\alpha = -0.9898$$
$$\beta = 0.2885$$
$$\gamma = -0.3703$$
$$\delta = -0.6856$$

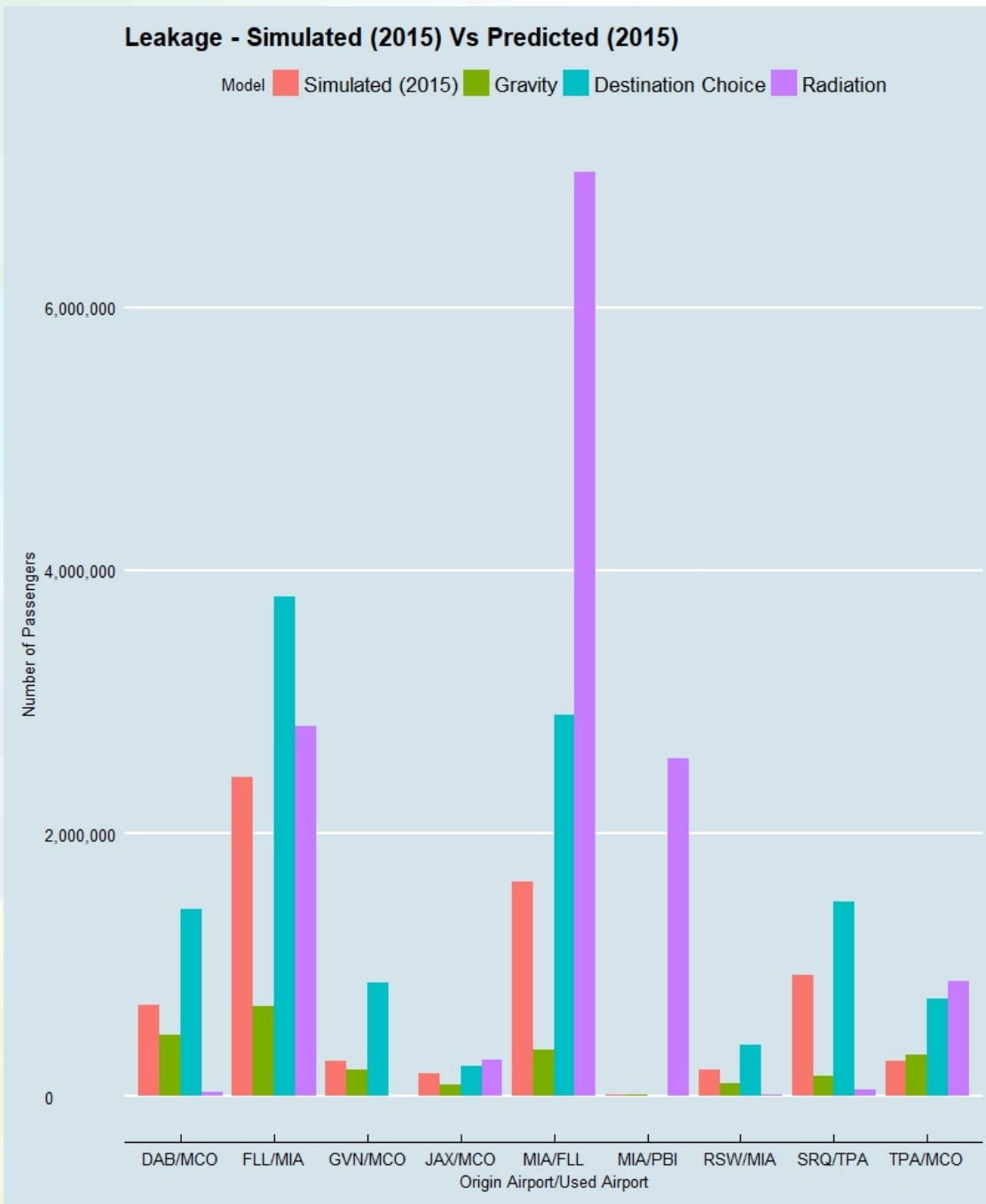*Source: Simini, Filippo, et al. "A universal model for mobility and migration patterns." *Nature* 484.7392 (2012): 96.
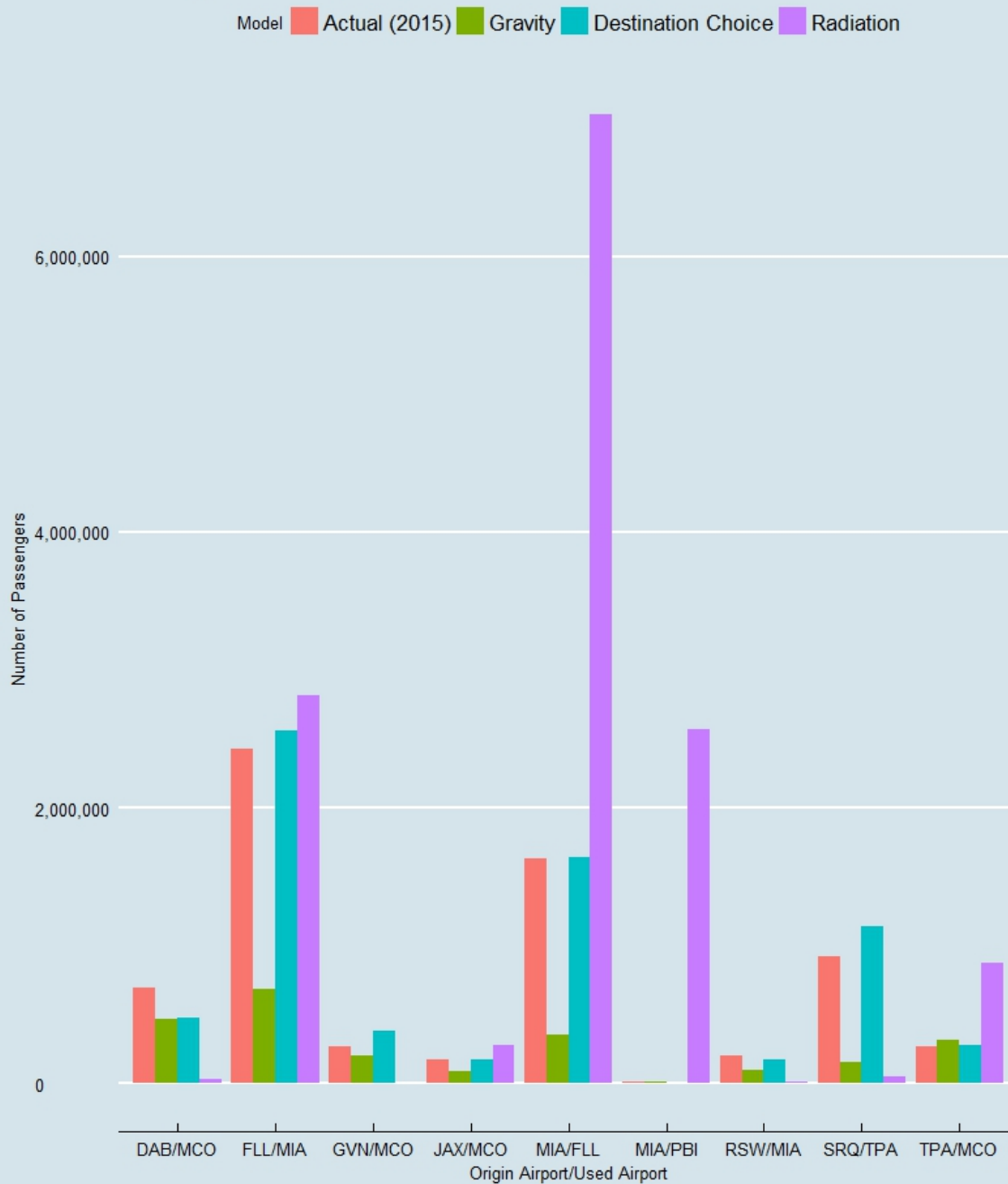
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Methodology

➔ Determine the number of passengers who end up in locations outside of the county where the airport is located.

» The model is trained to detect the leakage

➔ Used epidemic model to calculate risk of disease propagation from Puerto Rico to each of the counties

➔ Compare this risk with the reported infections in 2016

» Provides risk profile for disease propagation

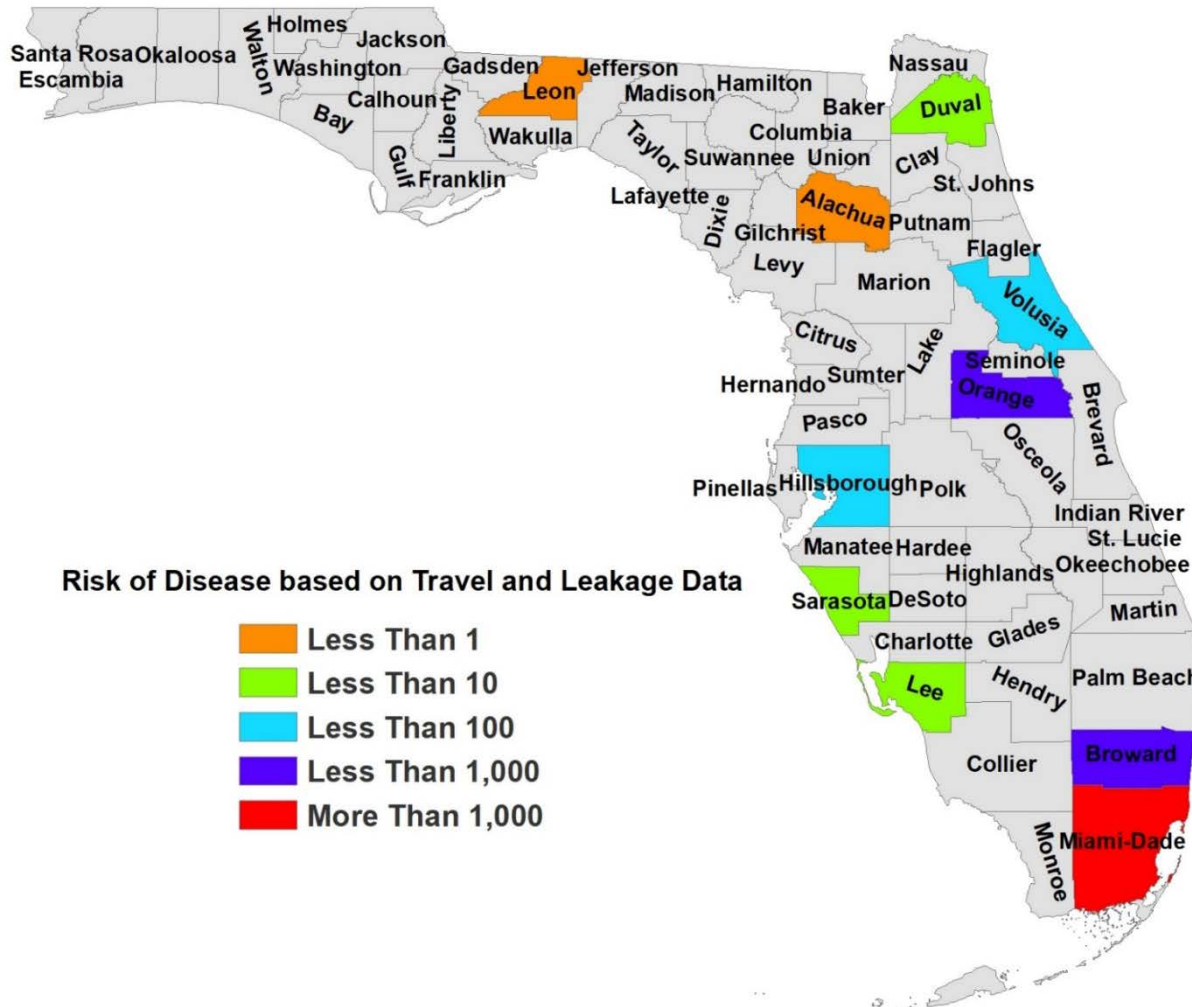CAMBRIDGE SYSTEMATICS

Results

Results

Results

Risk of Disease based on Travel and Leakage Data

- Orange: Less Than 1
- Green: Less Than 10
- Cyan: Less Than 100
- Purple: Less Than 1,000
- Red: More Than 1,000

County	Travel	Local	Total
Miami Dade	350	287	681
Broward	182	1	183
Orange	167	0	167
Volusia	12	0	12
Hillsborough	46	0	46
Duval	11	0	12
Leon	2	0	2
Sarasota	5	0	5
Lee	15	0	15
Alachua	12	0	12

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Risk of Infection
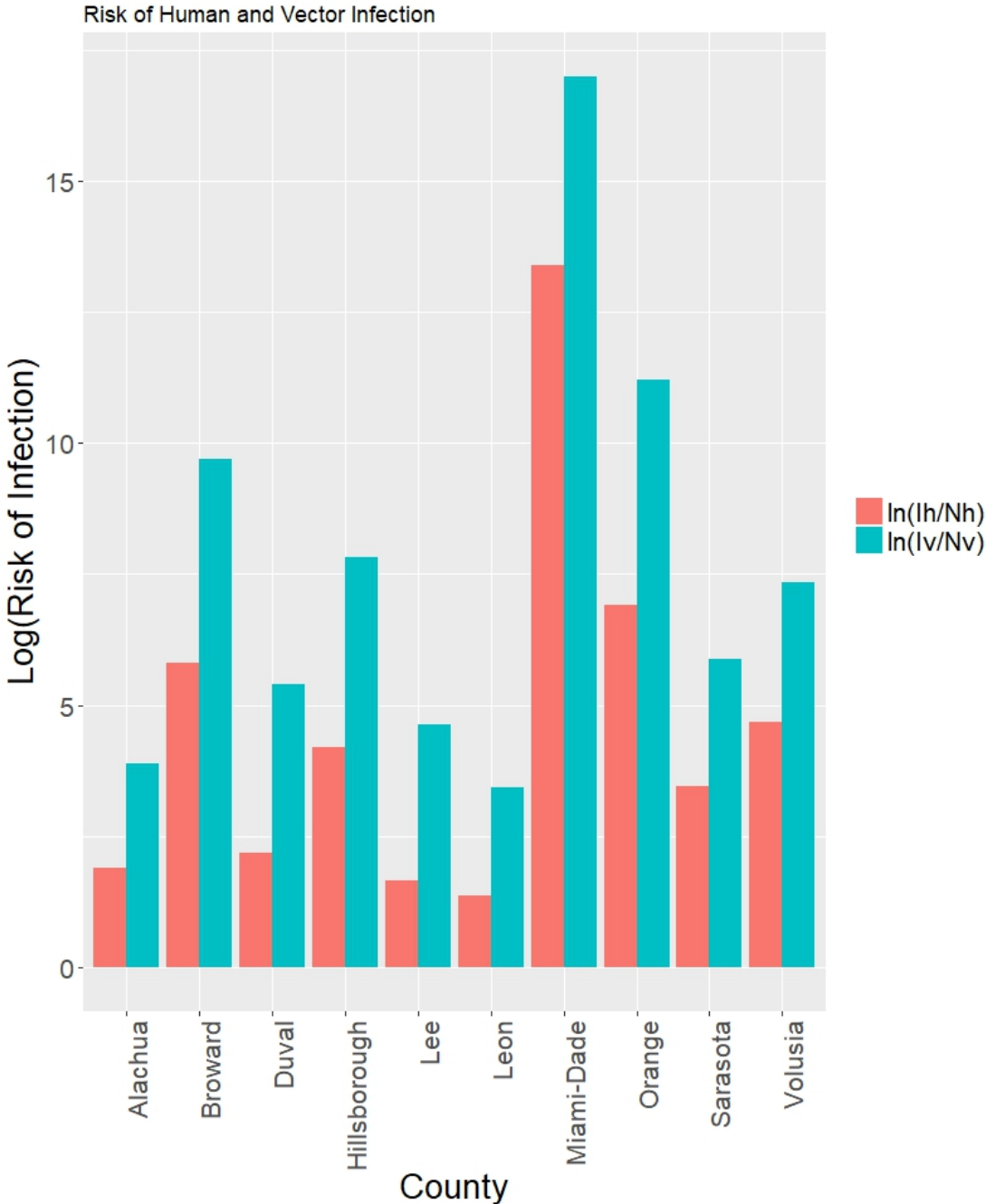
Twitter Data

➤ Processed more than 500,000 Twitter users tweets

  » 100 GB of tweets

  » Detected people from Puerto Rico with Twitter activities in Florida

  » Analyzed them to extract the tweet locations

➤ Compared popular places in Miami for Puerto Ricans with CDC red area designated zones for Zika

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CDC designated Red Areas versus Twitter Data

➜ Red Area designation for Zika:

  » Miami beach: December 9, November 21, August 19, September 17

  » Wynwood: September 19, August 1

  » Little River : December 2, October 13

➜ Popular Tweet's location in Miami for Puerto Ricans:

Neighborhood	Tweets with Geo-tag
Miami International Airport (MIA)	203
Marlins Park	171
The Wynwood Walls	168
InterContinental Miami	163
Miami Beach	119

https://www.cdc.gov/zika/intheus/florida-update.html

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Summary and Next Steps

- ➜ Predict the risk of disease infection which will propagate with travelers

- ➜ Determine risk for each county

- ➜ Destination choice seems to work well (compared to other models)

- ➜ Social media can be a potential source for real time disease location
  - » Need to be careful about using it though

- ➜ Additional demographic variables to refine the destination choice model

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