GeoDI Lab
GEOSPATIAL DATA INTELLIGENCE

Exploring the Scaling Relationships between Human Mobility and Air Pollutants in the Twin Cities

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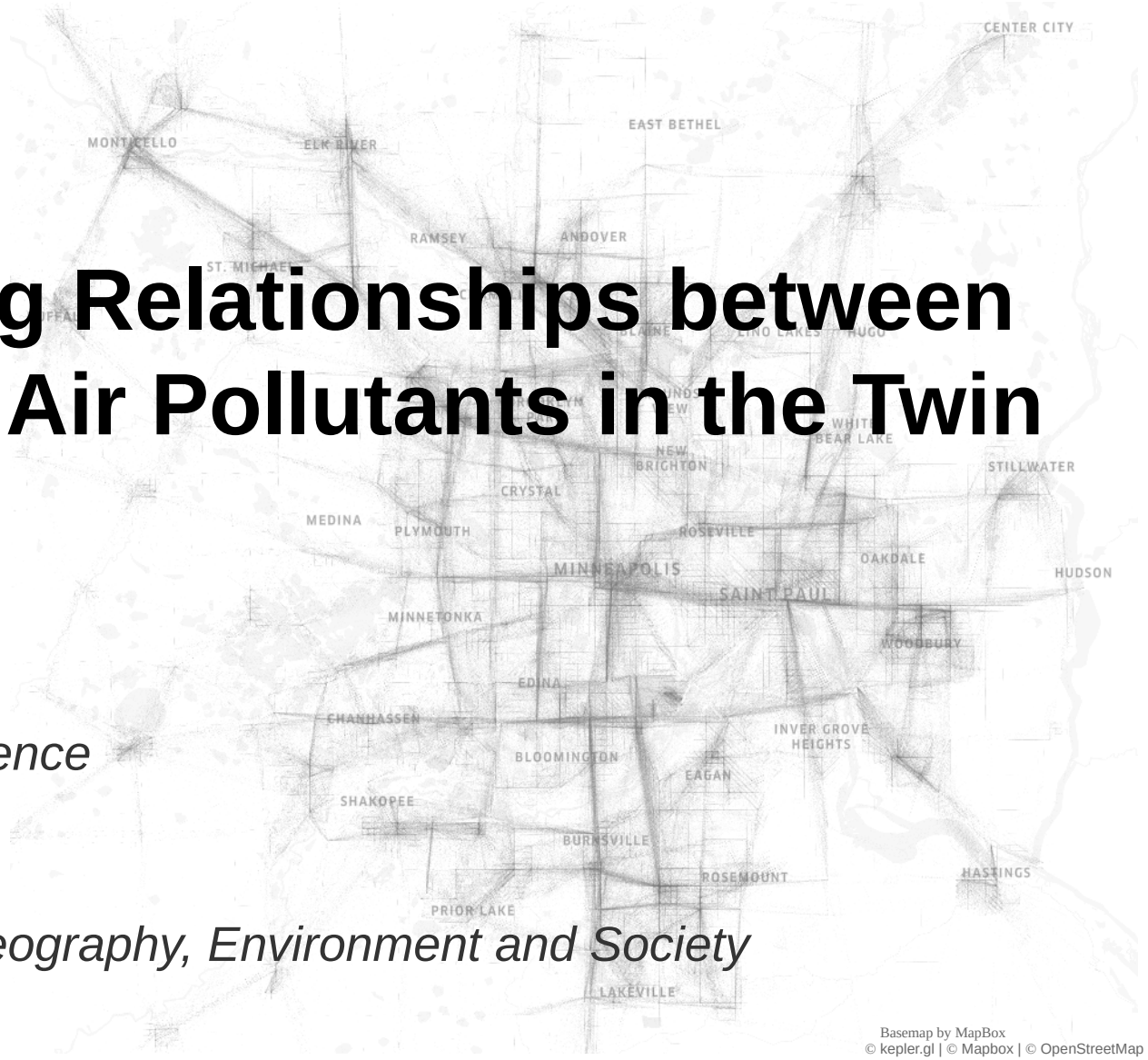


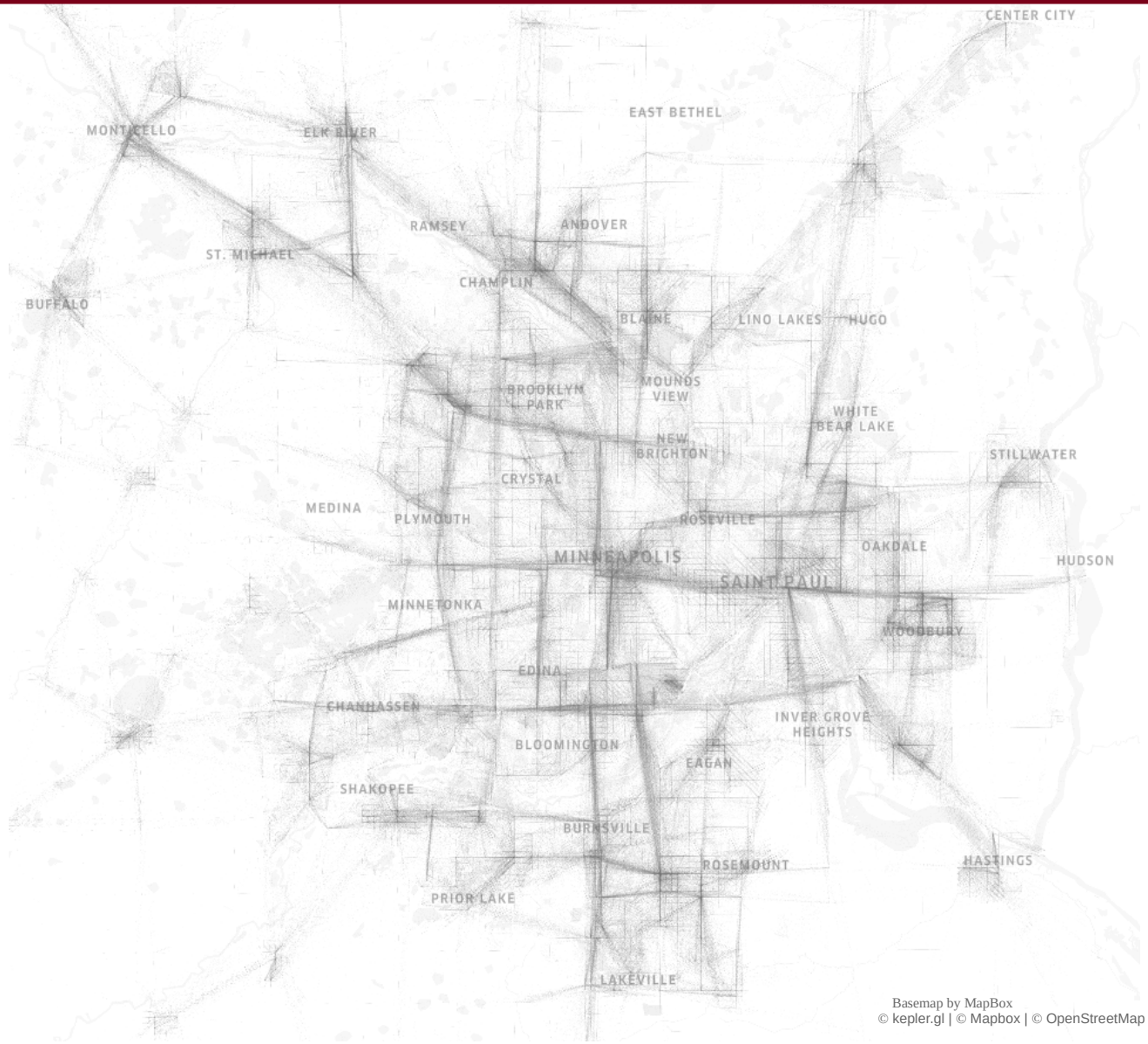
Agenda

I Background

II Data Description

III Preliminary Findings

IV Future Directions



Background

I Background

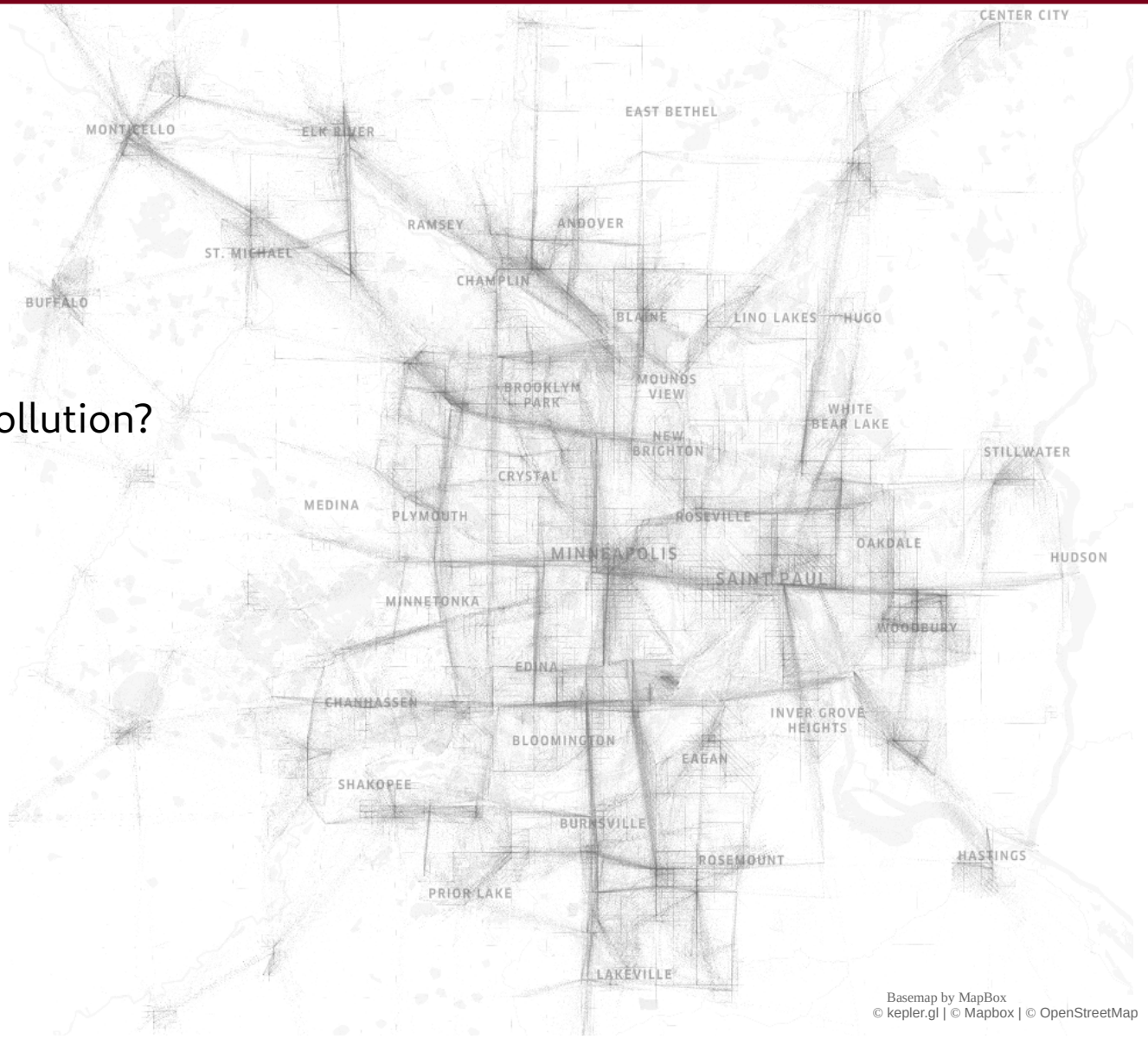
a What is Scaling?

b Why Mobility & Air Pollution?

II Data Description

III Preliminary Findings

IV Future Directions

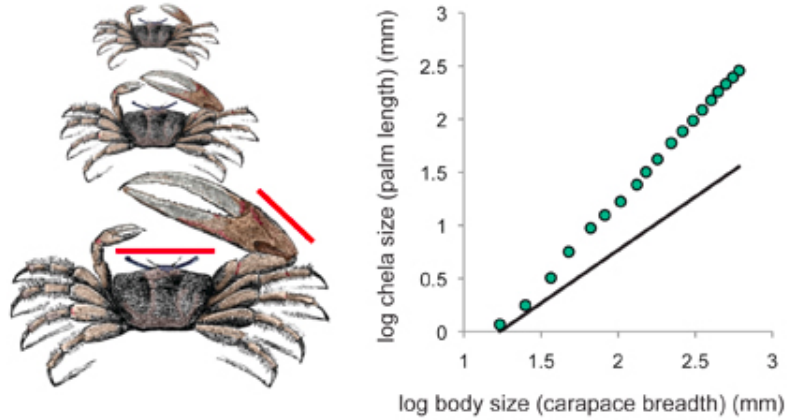


Scaling: Allometric Growth

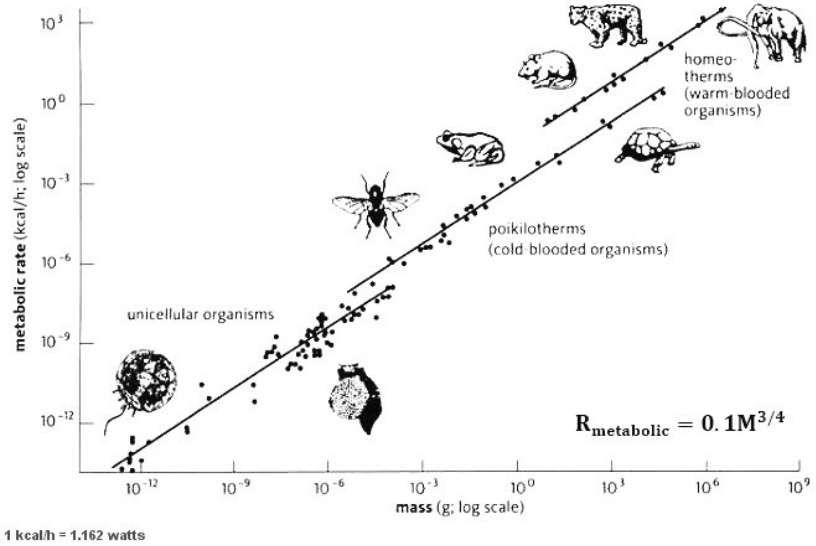
- **Definition:** How do two traits or processes scale with one another?

- **Universal power laws** (log-log relationships) have been observed in biological phenomena for over 100 years
  - E.g. Fiddler Crab claw grows faster than rest of body

- Similarly, ecosystems have these properties
  - Researchers have recently found power laws apply to urban systems as well



From: Shingleton, A.(2010)
Allometry: The Study of Biological Scaling. Nature Education Knowledge 3(10):2



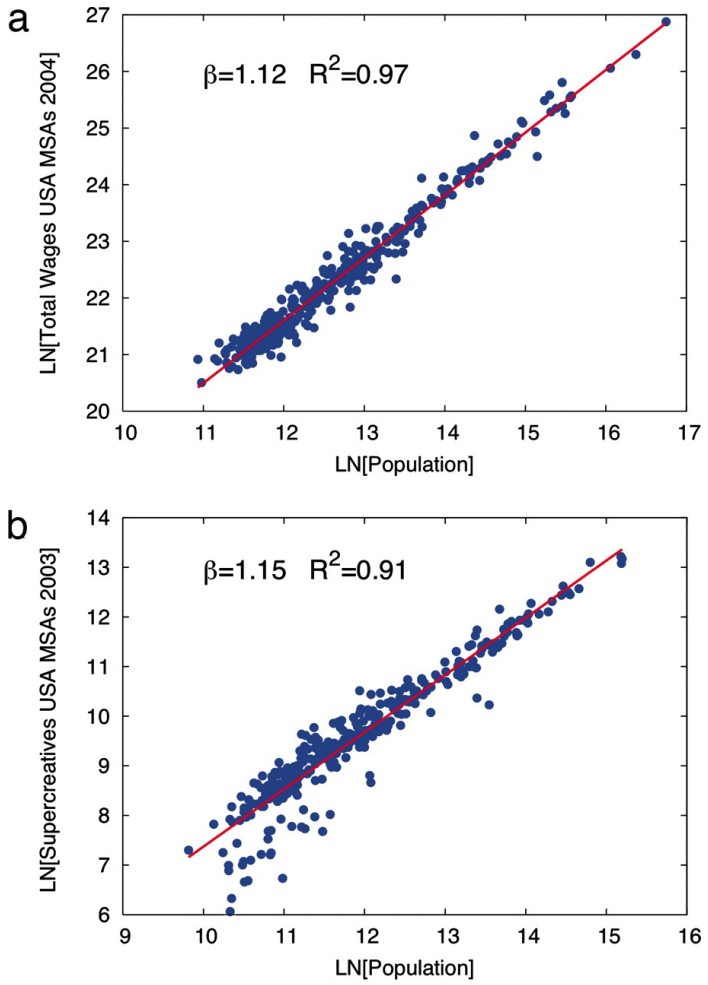
From: https://universe-review.ca/R10-35-metabolic.htm

Scaling: Urban Systems

- Typically done through an economics lens
  - Comparing the size of an urban system (population) to another urban indicator

- Three main categories of urban scaling:
  - **Linear -** individual needs, e.g. Water Consumption
  - **Sub-linear -** economies of scale, e.g. Road Networks
  - **Super-linear -** increasing returns, e.g. Total Wages

- We apply the same analysis to explore how emissions (the indicator) scale with human mobility (the size)
  - Investigating the **efficiency of a transportation system**



From: L. M. A. Bettencourt, J. Lobo, D. Helbing, C. Kühnert, G. B. West, Growth, innovation, scaling, and the pace of life in cities. Proc. Natl. Acad. Sci. U.S.A. 104, 7301–7306 (2007). https://doi.org/10.1073/pnas.0610172104

Why Mobility & Air Pollution?

- We are in the **Anthropocene!**
  - Forever chemicals, waste, deforestation, …
  - Transportation emissions are a large part of this
- Air pollution not only destabilizes our climate, it also **impacts human health**
- We need metrics to **quantify** and **compare** our **transportation systems**

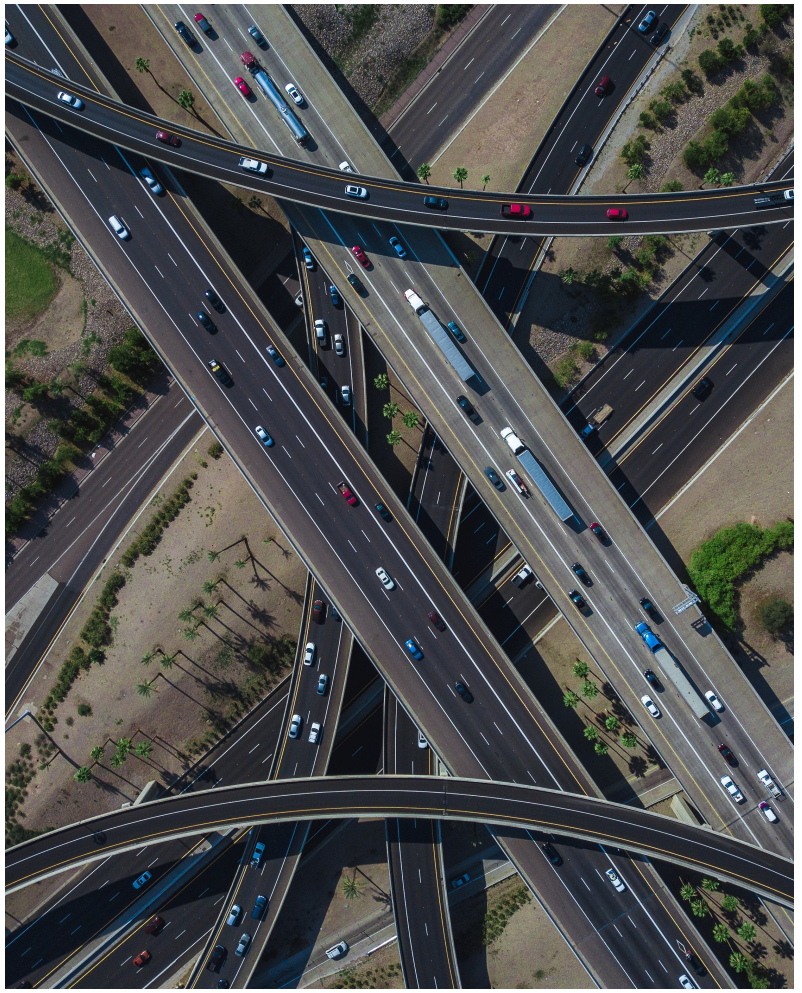
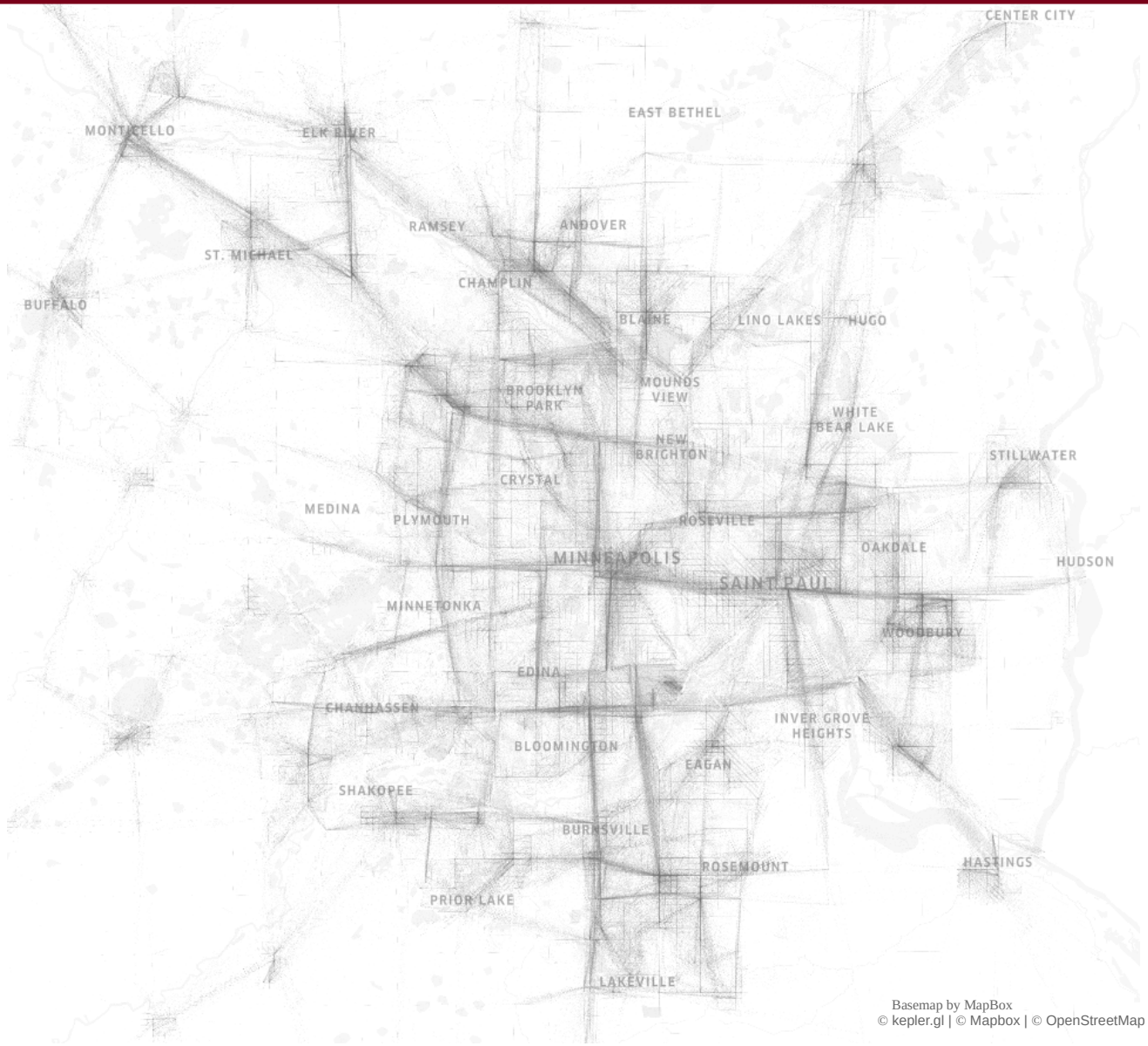


Photo from Jared Murray on Unsplash

Data Description



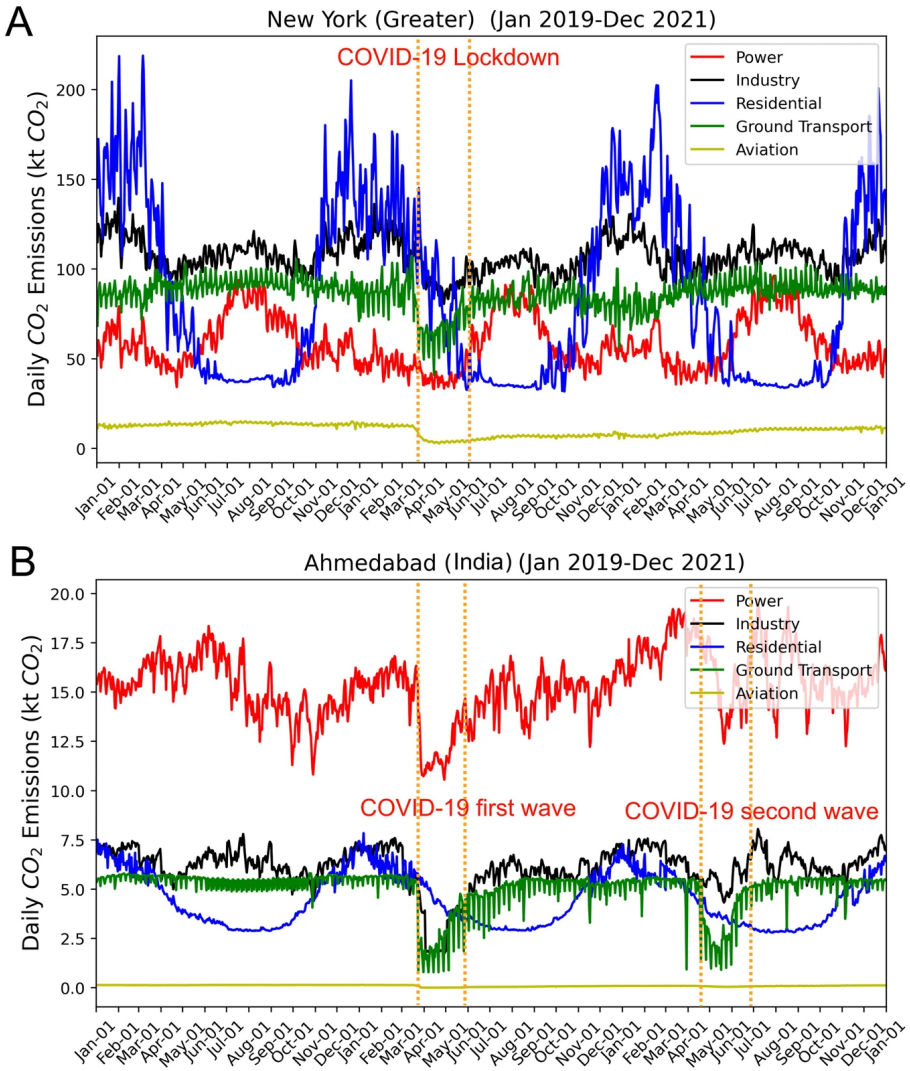
Data Description

Carbon Emissions

- From the paper, **Carbon Monitor Cities near-real-time daily estimates of CO2 emissions from 1500 cities worldwide**

- Modeled Daily kilotons of CO_2 by sector across the Globe
  - At country, county, and city level
  - Counties in our study area:
    - **Ramsey** - State Capitol
    - **Hennepin** - Largest Population
    - **Dakota** - Suburban

- Current Estimates at CarbonMonitor.org



From: Huo, D., Huang, X., Dou, X. et al.
Carbon Monitor Cities near-real-time daily estimates of CO2 emissions from 1500 cities worldwide.
Sci Data 9, 533 (2022). https://doi.org/10.1038/s41597-022-01657-z

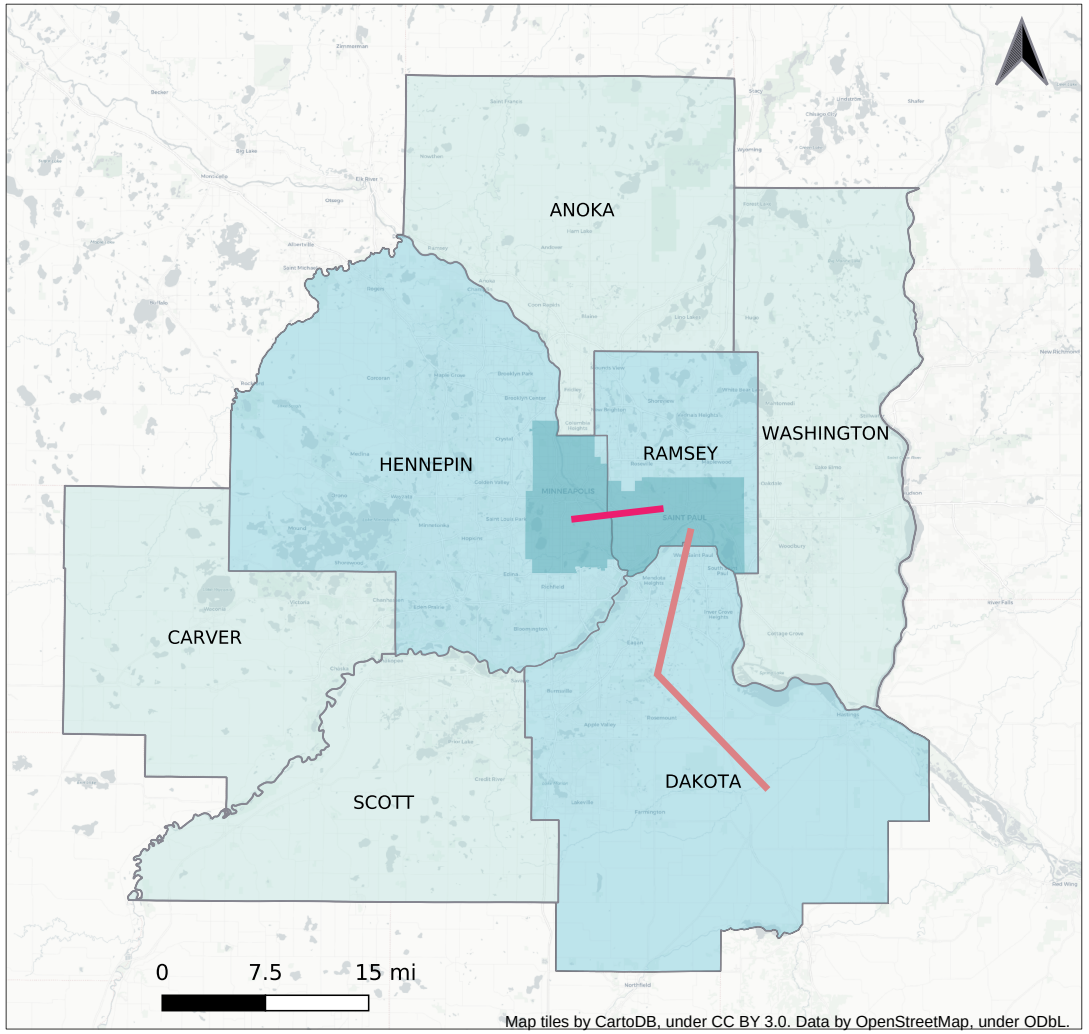
Data Description

Human Mobility

- Proprietary data of mobile device trajectories
  - Anonymized unique devices
  - Within seconds & meters
  - For the entire United States

- Used to compute basic daily mobility indices for the whole system:
  - Total Distance
  - Total Travel Time
  - Average Device Distance
  - Average Device Travel Time

Example Trajectories in 7 County Metro



Preliminary Findings

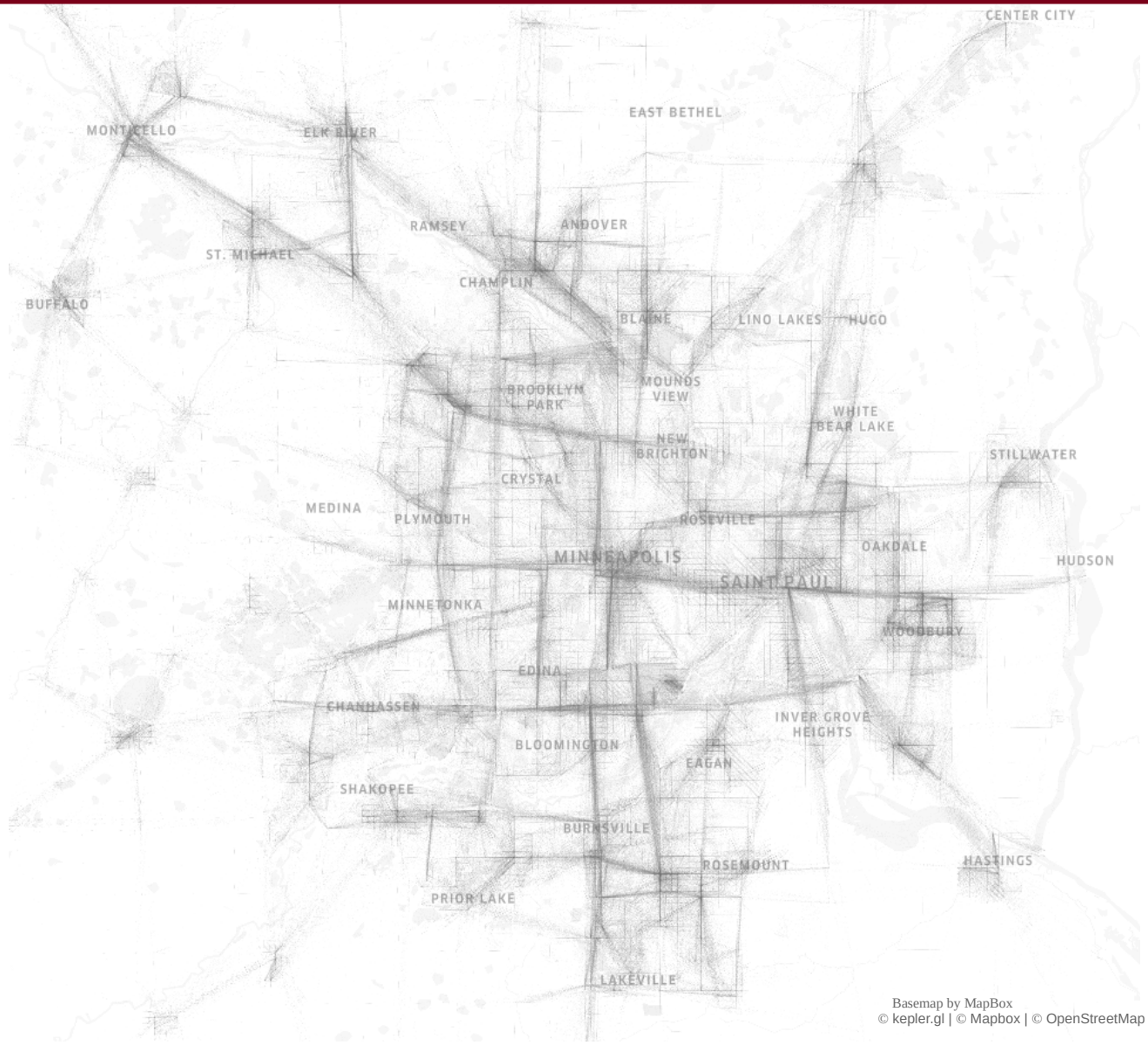
I Background

II Data Description

III Preliminary Findings

- a As One System
- b Multiple Systems
- c Spatial Findings
- d Temporal Findings

IV Future Directions

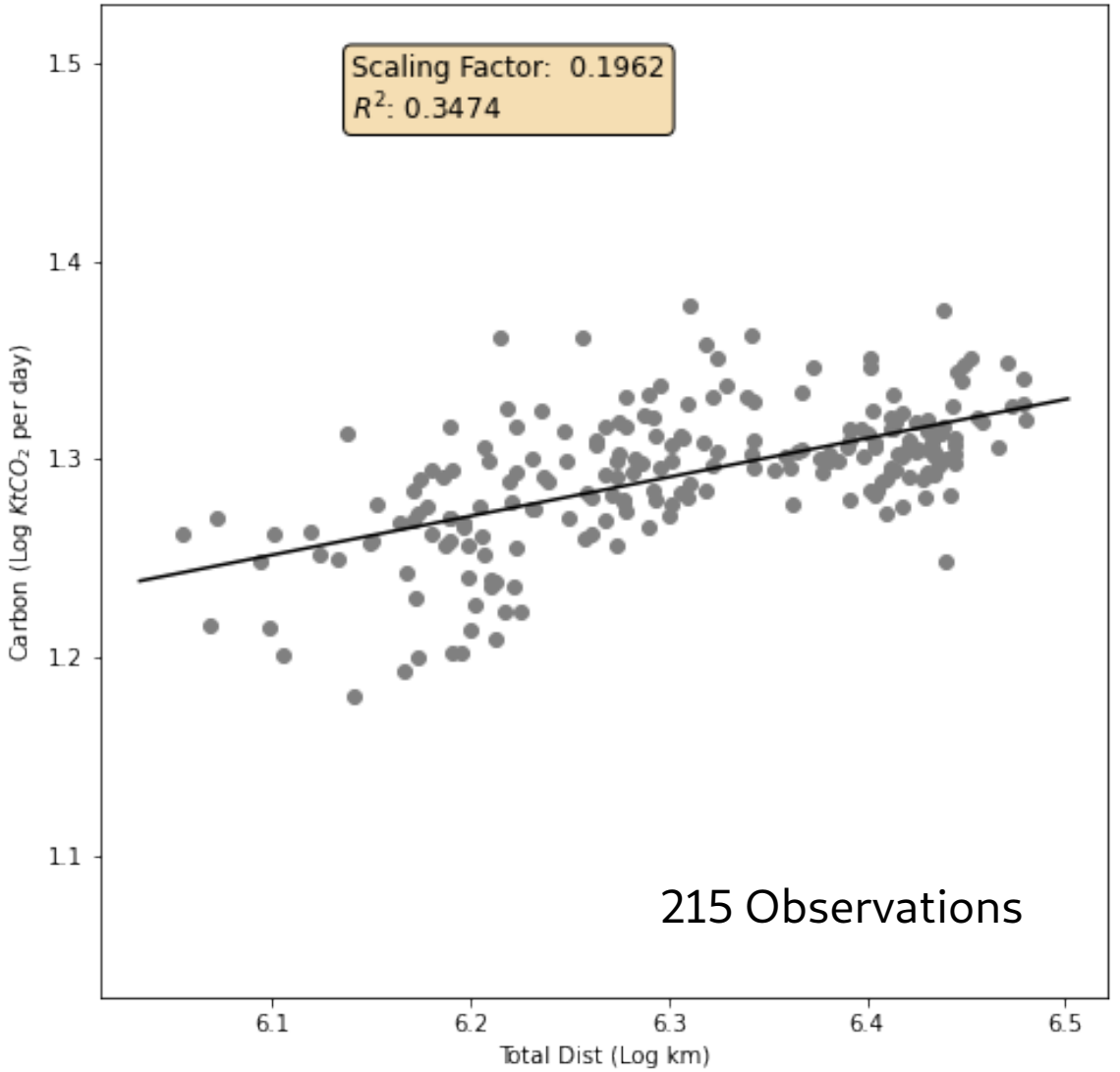


Preliminary Findings

As One System

- Studying the three counties as one system we find...
  - Carbon appears to have **sub-linear** scaling with distance traveled
  - The fit is not as good as other phenomena

Scaling of Total Distance & Ground Transport Emissions



Preliminary Findings

Separate Systems

- Different clusters appear when broken down to the county level

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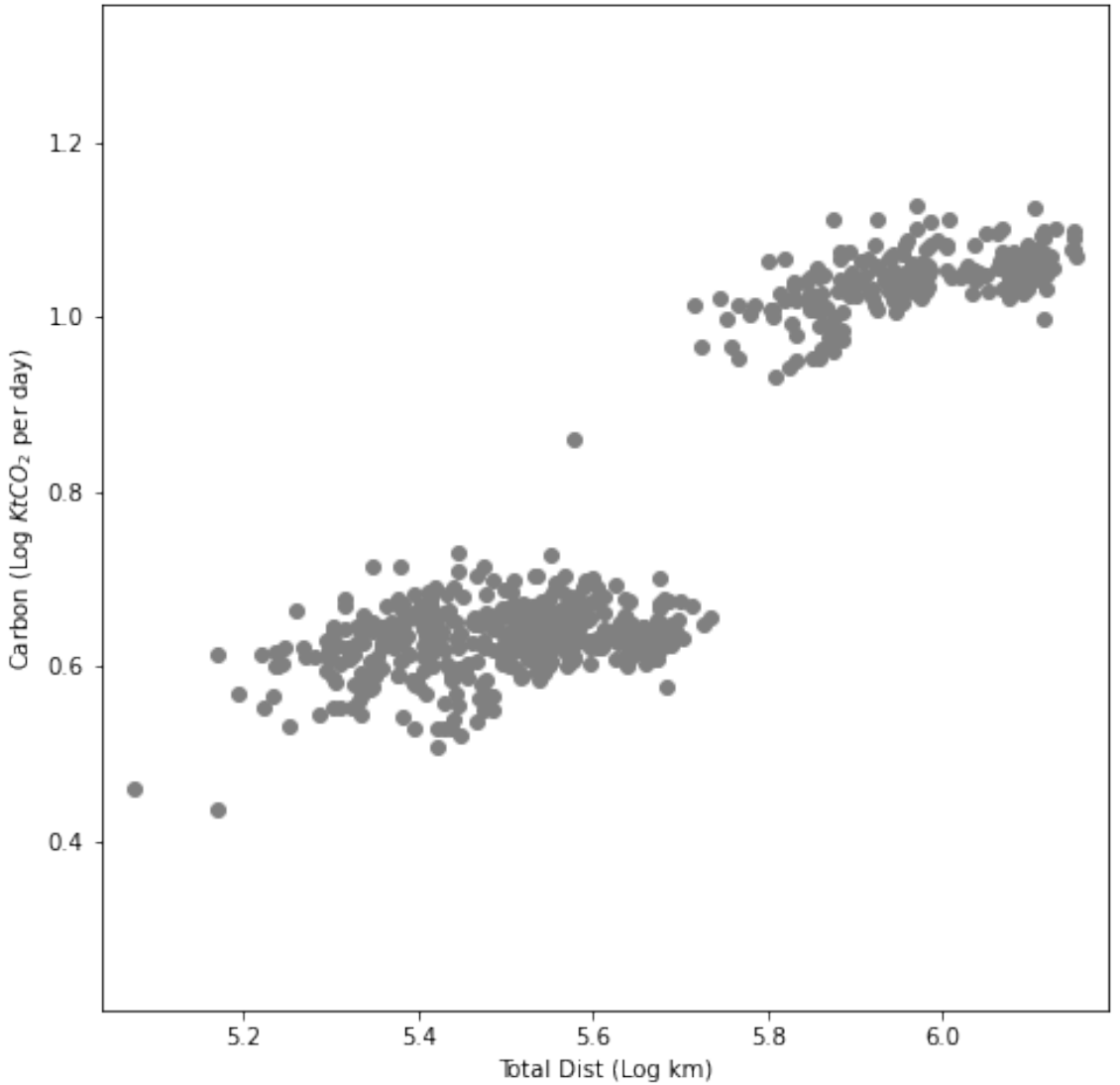

Preliminary Findings

Separate Systems

- Different clusters appear when broken down to the county level
  - Counties

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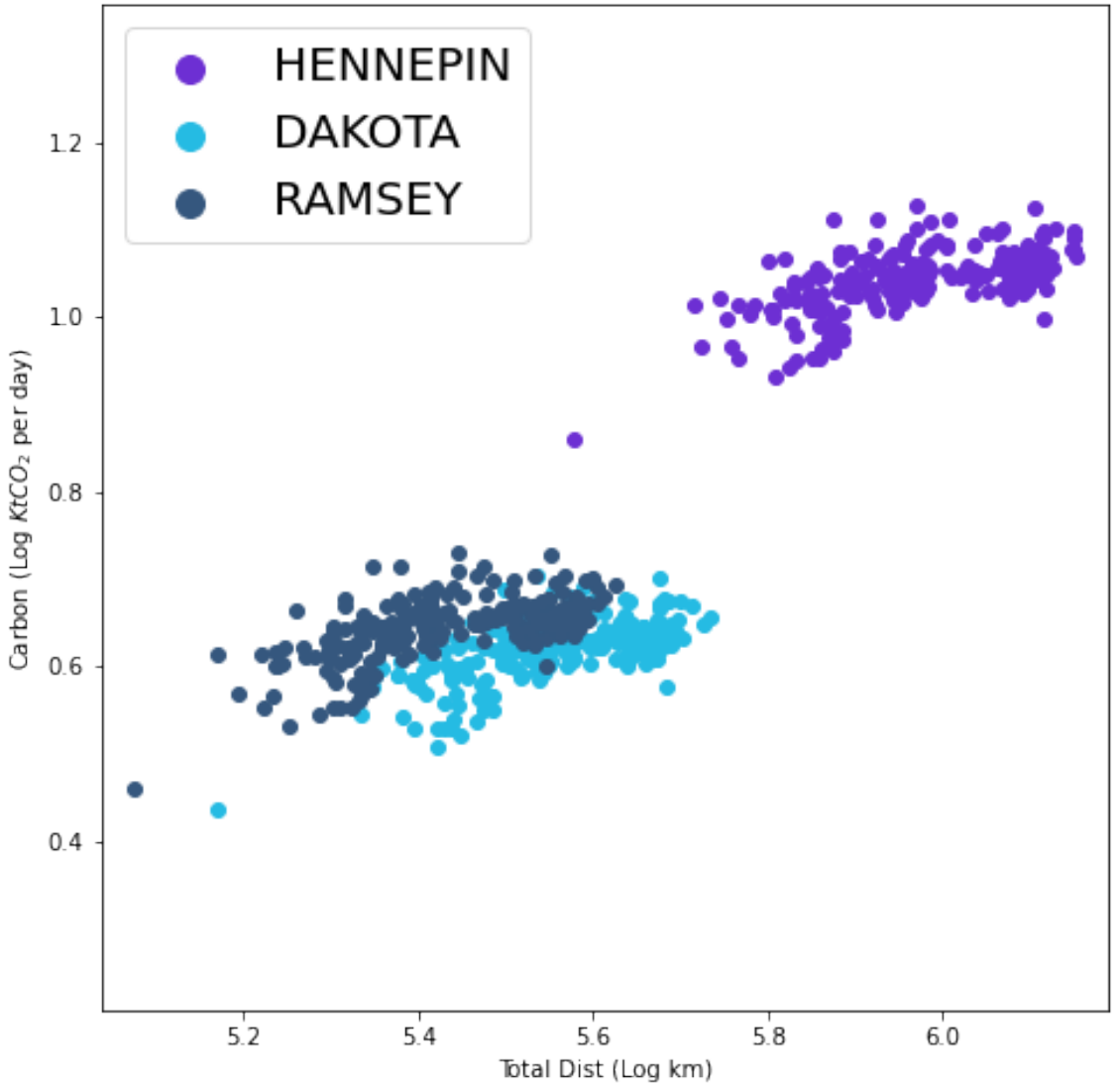

Preliminary Findings

Separate Systems

- Different clusters appear when broken down to the county level
  - Counties
  - Vaccine Availability

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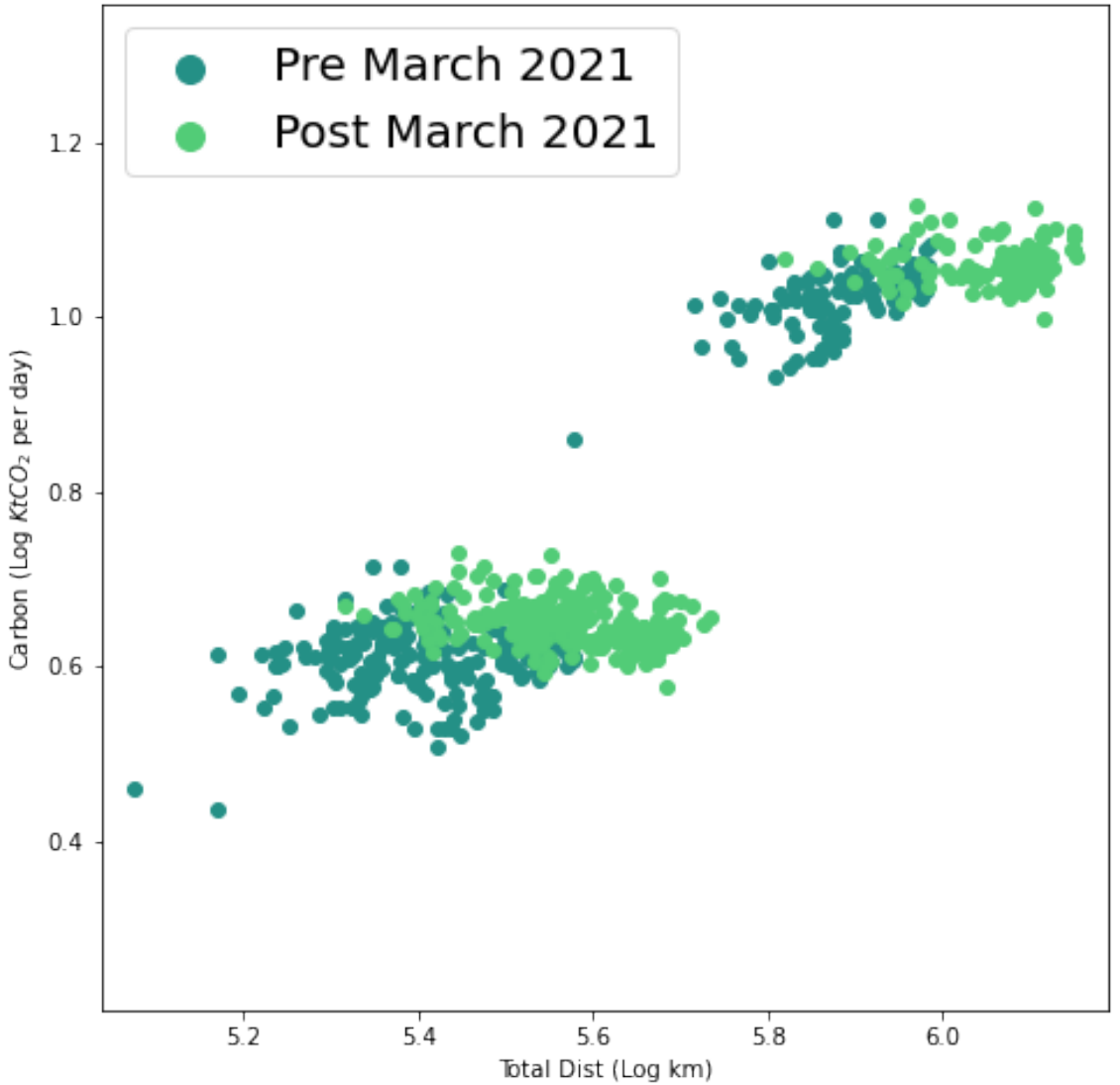
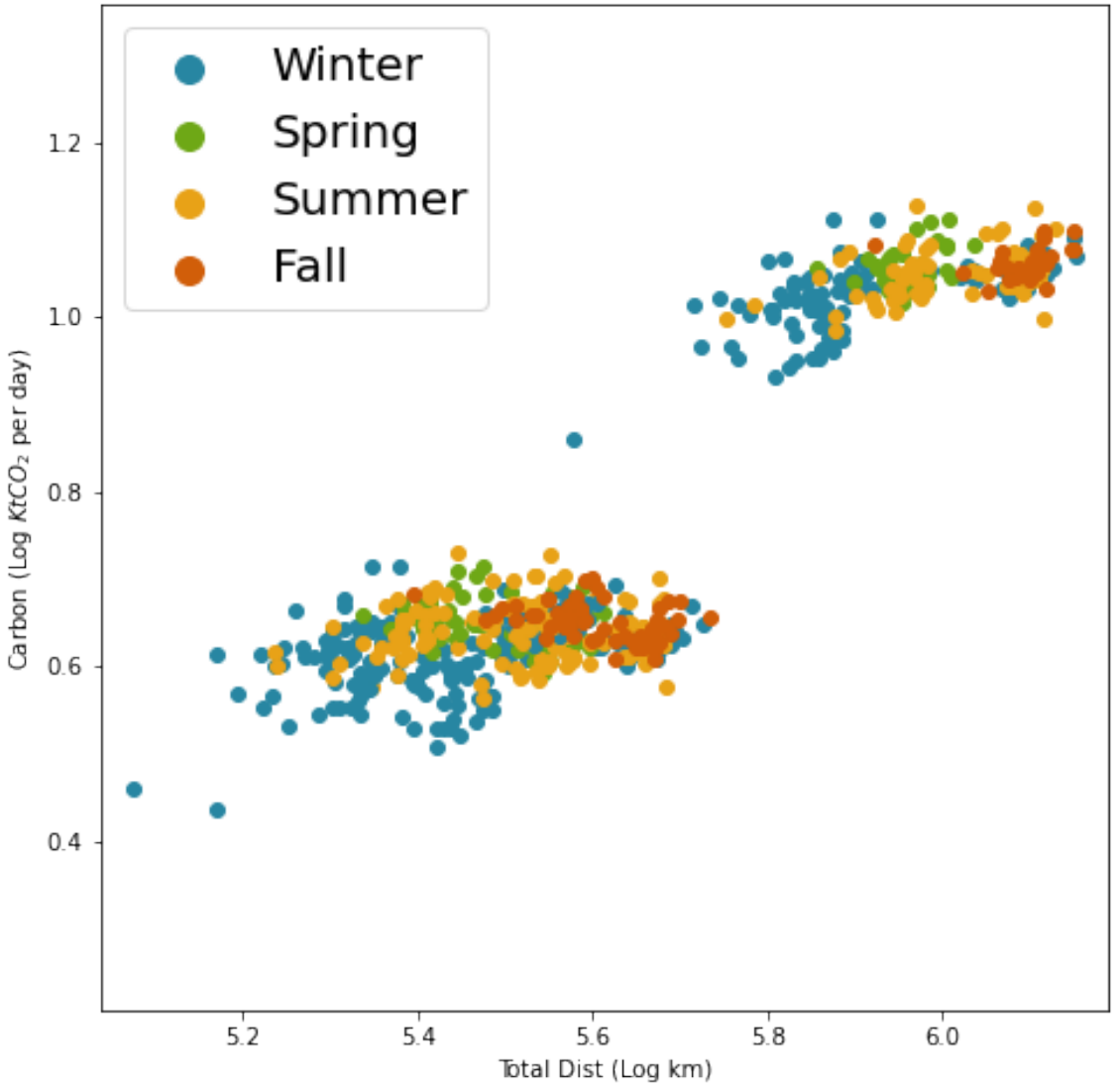


Preliminary Findings

Separate Systems

- Different clusters appear when broken down to the county level
  - Counties
  - Vaccine Availability
  - Seasons

Scaling of Total Distance & Ground Transport Emissions



Spatial Findings

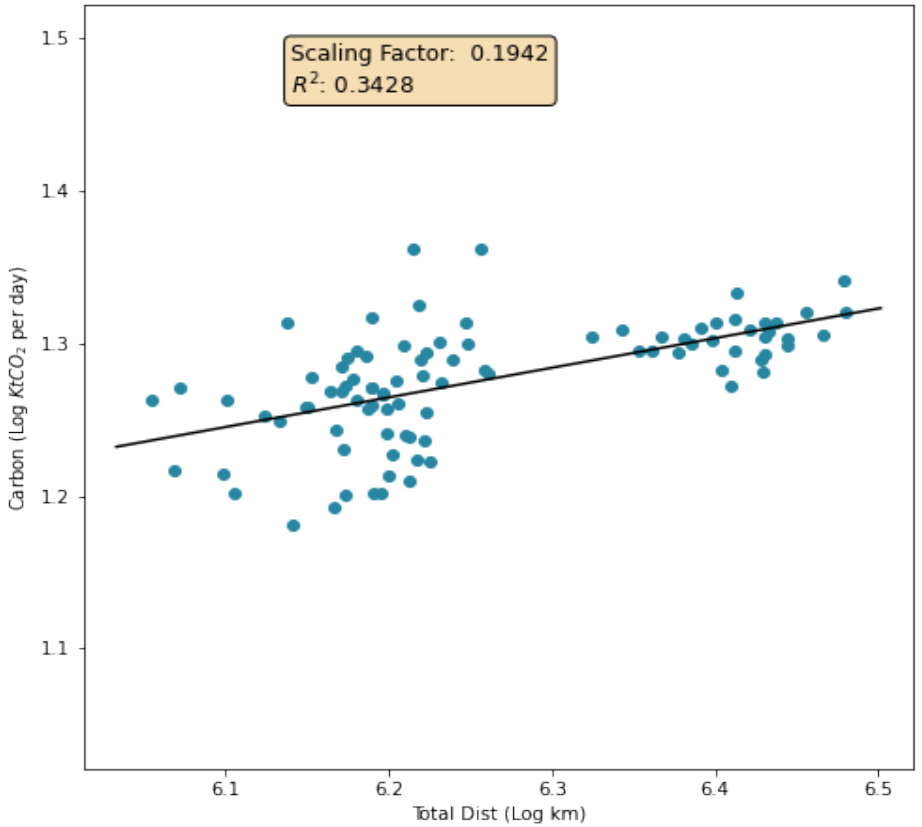
Mobility Index	County	Scaling Factor	95% Confidence Interval	Adjusted R2
Total Distance	HENNEPIN	0.186	[0.151 0.221]	0.336
	RAMSEY	0.192	[0.156 0.227]	0.345
	DAKOTA	0.205	[0.165 0.245]	0.325
	Combined	0.196	[0.160 0.232]	0.347
Total Travel Time	HENNEPIN	0.184	[0.149 0.220]	0.333
	RAMSEY	0.188	[0.152 0.223]	0.336
	DAKOTA	0.200	[0.160 0.240]	0.308
	Combined	0.194	[0.158 0.230]	0.341
Average Device Distance	HENNEPIN	0.608	[0.486 0.730]	0.309
	RAMSEY	0.850	[0.690 1.010]	0.339
	DAKOTA	0.574	[0.452 0.697]	0.285
	Combined	0.576	[0.473 0.679]	0.362
Average Device Travel Time	HENNEPIN	0.514	[0.400 0.627]	0.269
	RAMSEY	0.612	[0.466 0.759]	0.240
	DAKOTA	0.478	[0.358 0.599]	0.220
	Combined	0.551	[0.450 0.653]	0.348

Temporal Findings

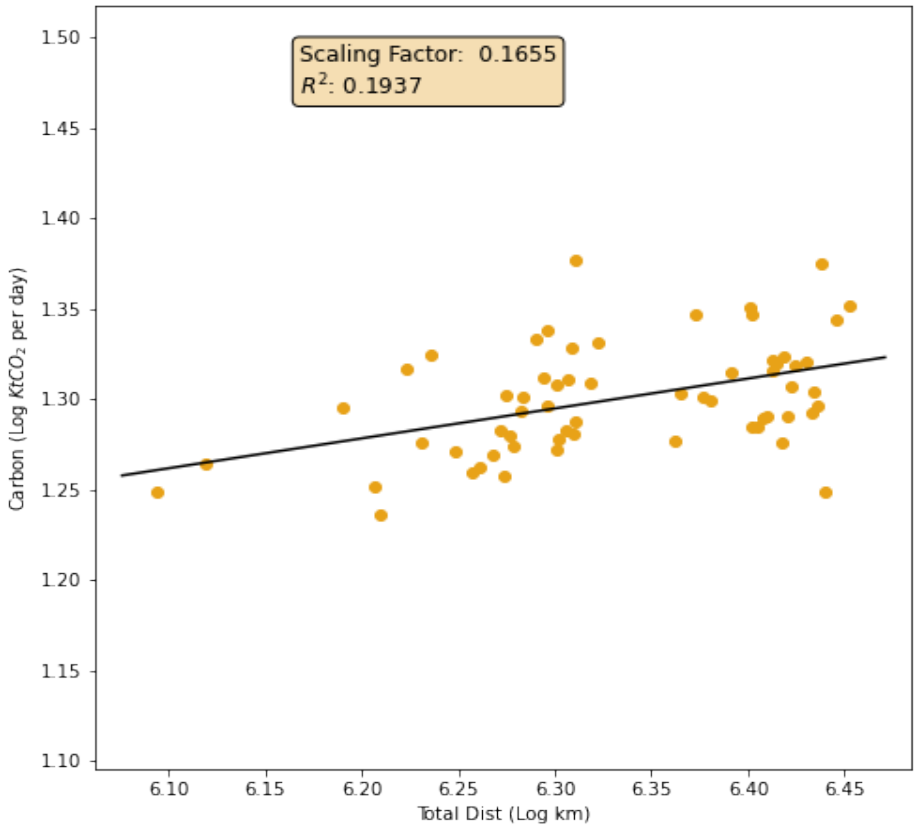
Seasonality in Scaling of Total Distance & Ground Transport Emissions

(As One System)

Winter



Summer



Future Directions

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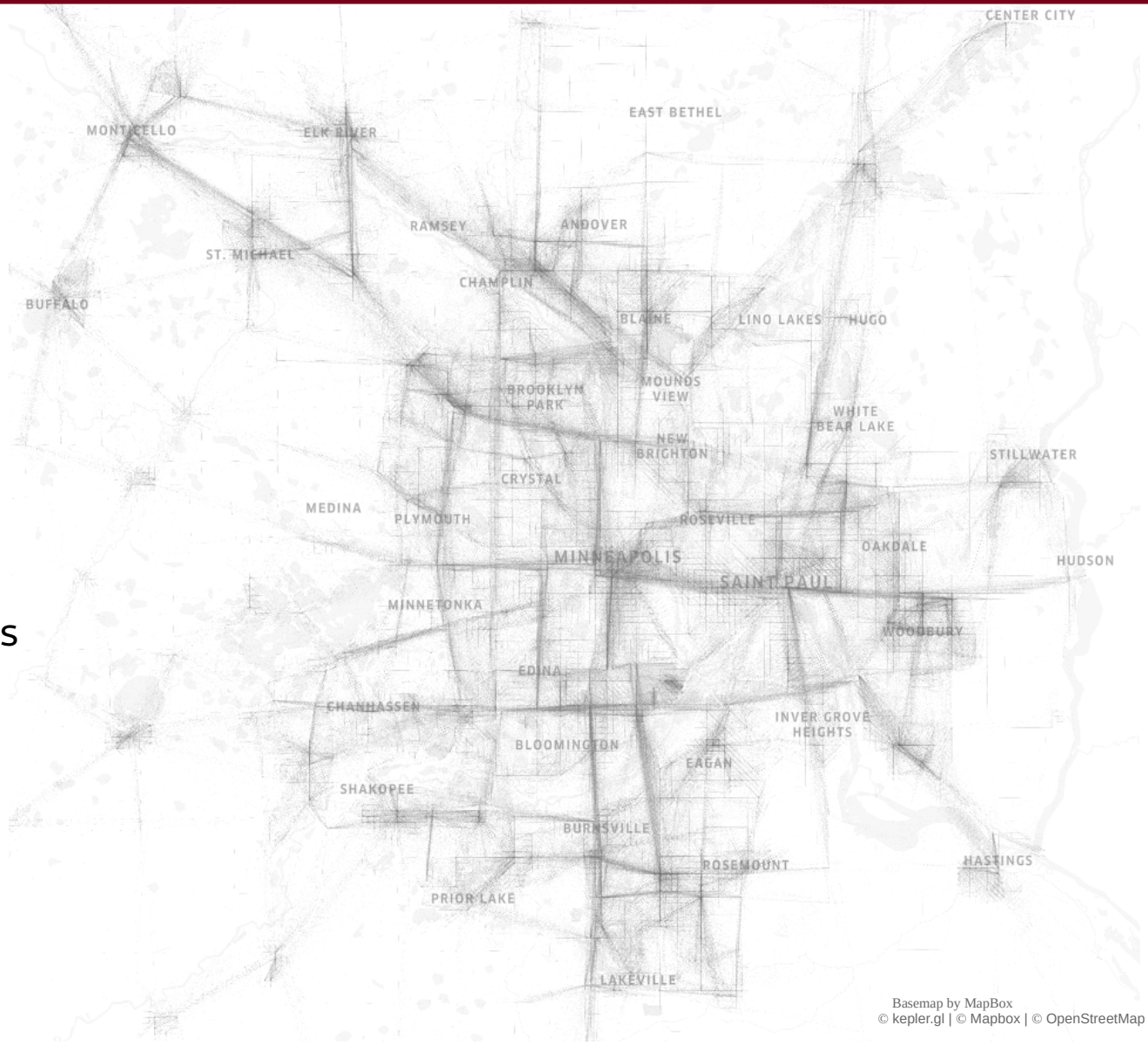
- a Other Pollutants
- b Other Mobility Indices
- c Applications



Other Pollutants

- Pollutants of concern from vehicles:
  - Carbon, Particulate Matter (PM), Volatile Organic Compounds (VOCs), …
- The American Heart Association established a **causal link between Particulate Matter & Heart and Lung Disease**
- Spatial Distribution
  - Local variation is important with PM & VOCs
  - Working-class, communities of color are disproportionately burdened

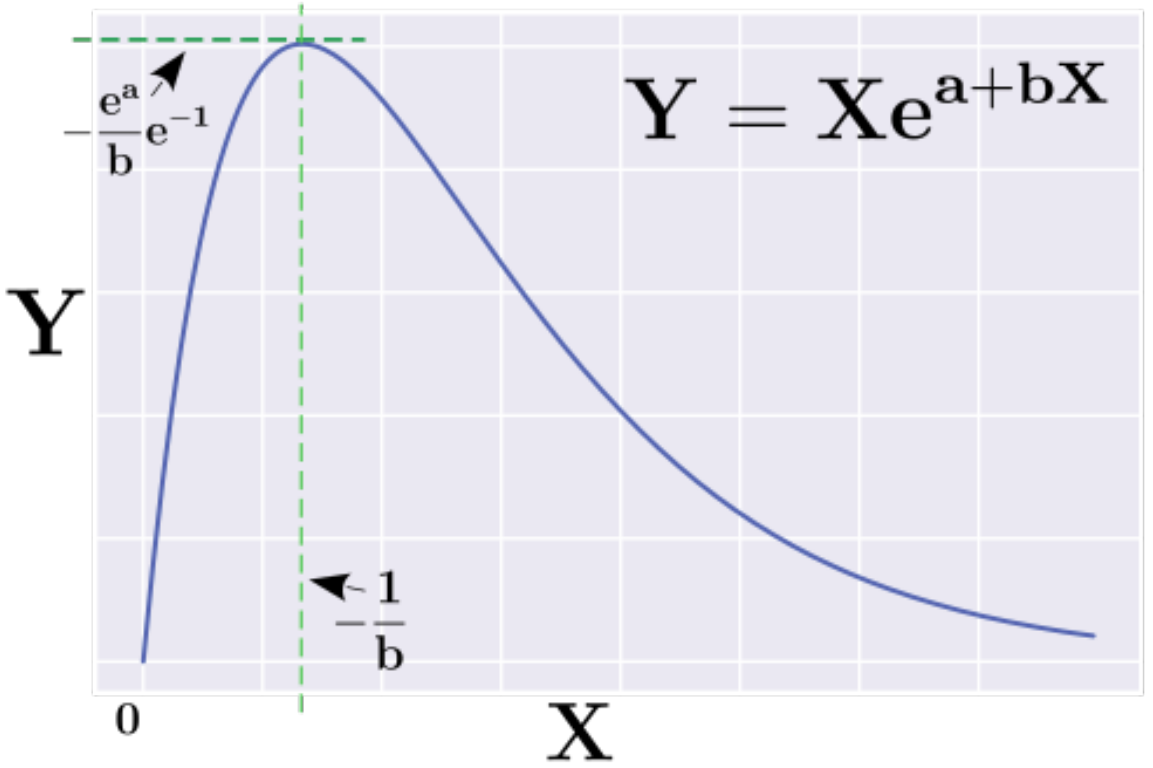
Photo from Photoholgic on Unsplash

Other Mobility Indices: Critical Distance

- The Ricker Curve is an ecological model
  - Growth Rate with Carrying Capacity
- Has mathematical properties
- Related to the power law used in typical human mobility analysis but considers **small scale mobility**
- Let **X = Distance**

  & **Y = Frequency** the distance is traveled

Ricker Model Equation



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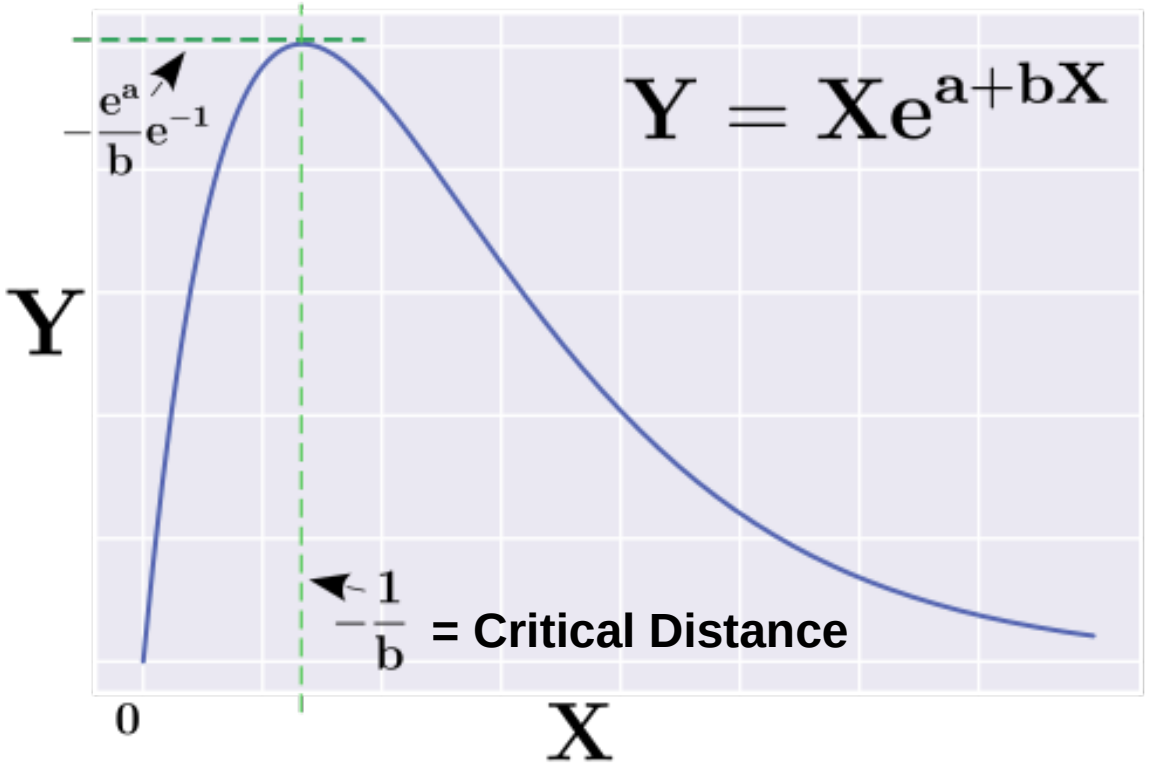

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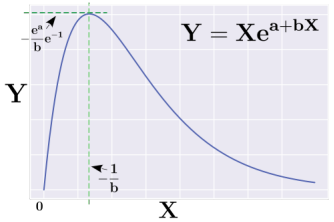

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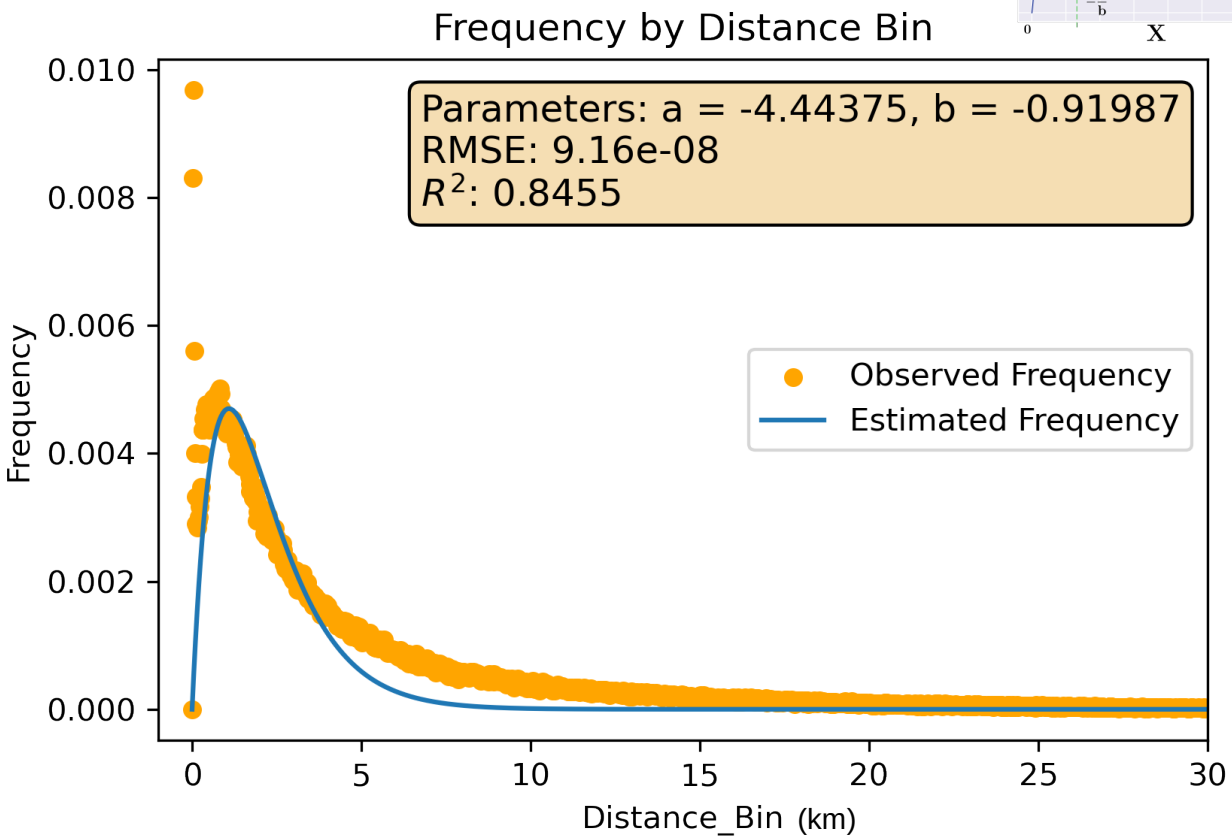
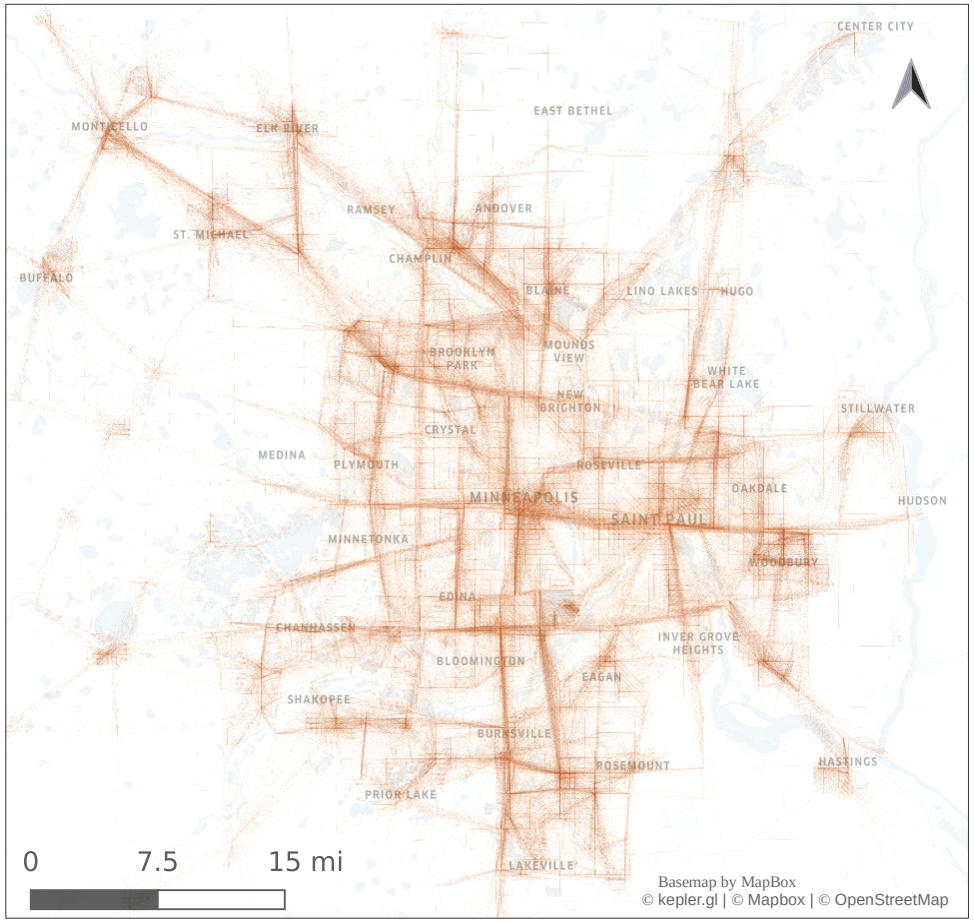


Applications

- **Efficiency of a transportation system**
  - Flexible framework
  - A method to classify & assess progress of metropolitan areas across the US
  - And deepen our understanding of the relationship between mobility and air pollution

Aggregated Trajectories

(July 2020 → Dec 2021)



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Special thanks to my family, housemates (the Toegels), Zhongfu Ma (PhD student), and Dr. Di Zhu for their support

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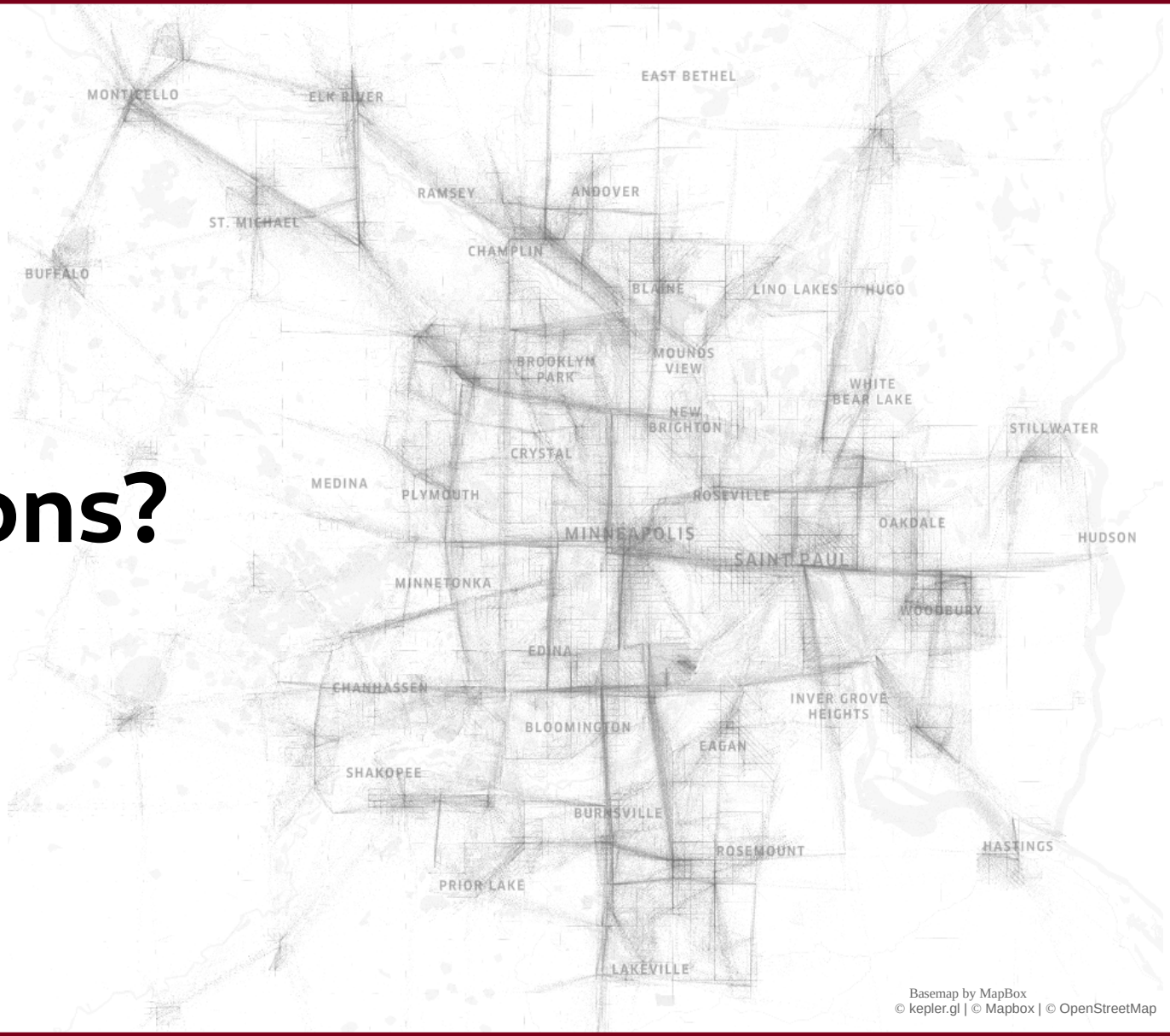
U-SPATIAL
Support for Spatial Research

GeoDI Lab
GEOSPATIAL DATA INTELLIGENCE

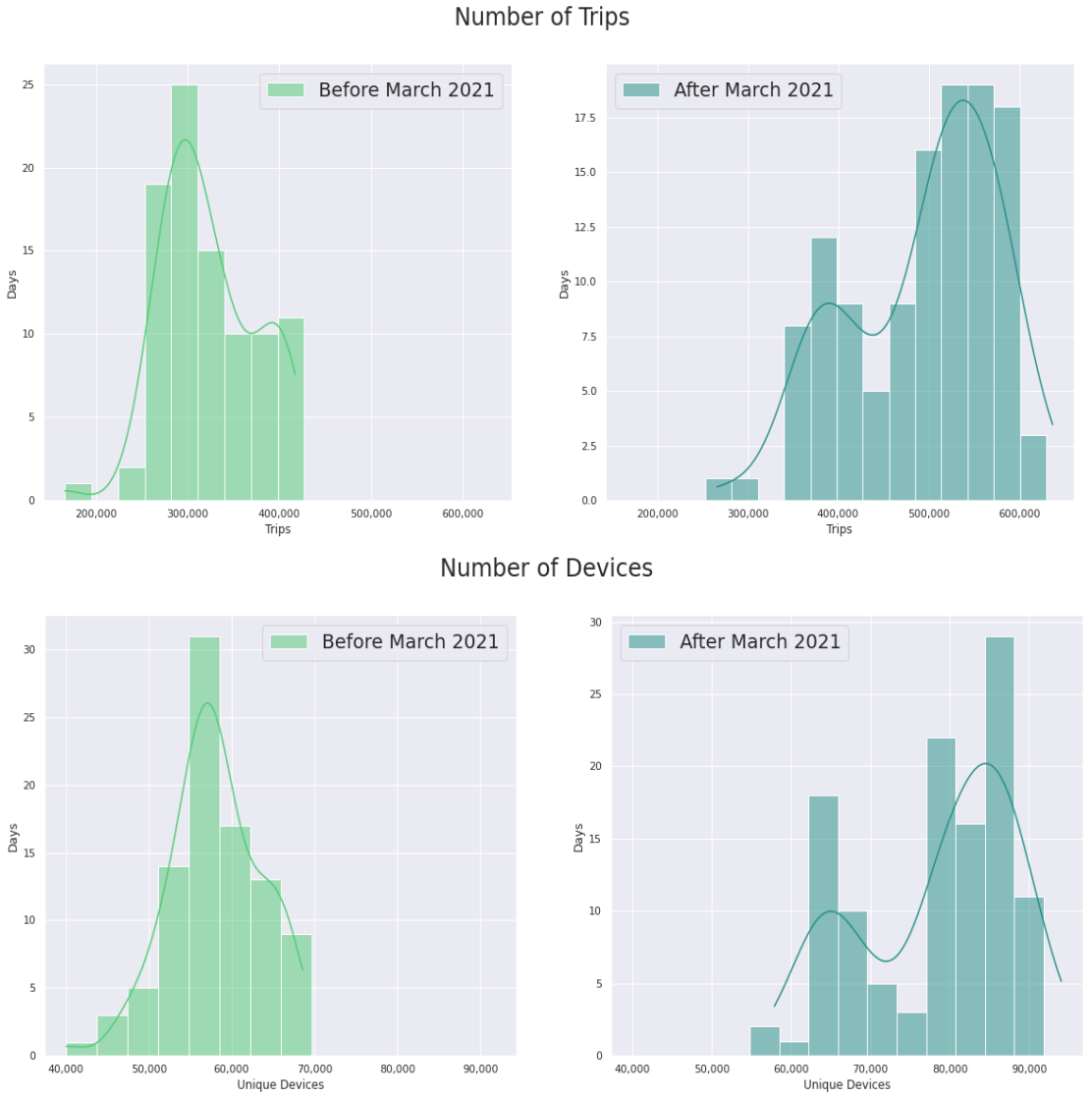
Thank you!

Questions?



Mobility Data & Index Quality

- Does this actually represent reality?
  - Biased to mobile device users with location services
  - Temporal variation in amount of data
  - Trajectory length computed “as the crow flies” (Euclidean Distance)
  - Defining extent to select trajectories introduces issues with Modifiable Areal Unit Problem



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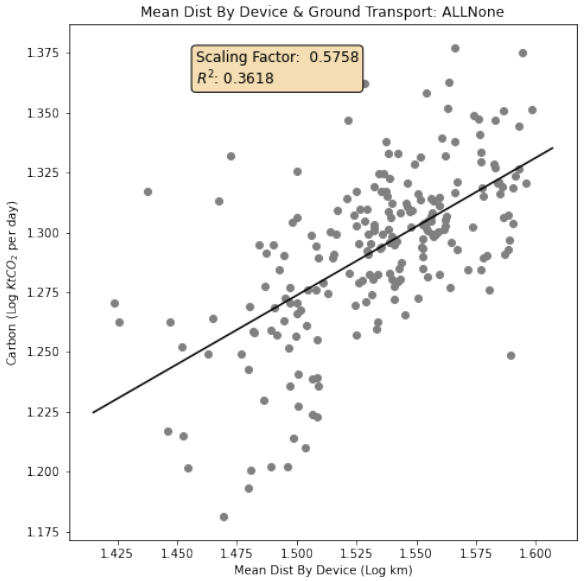
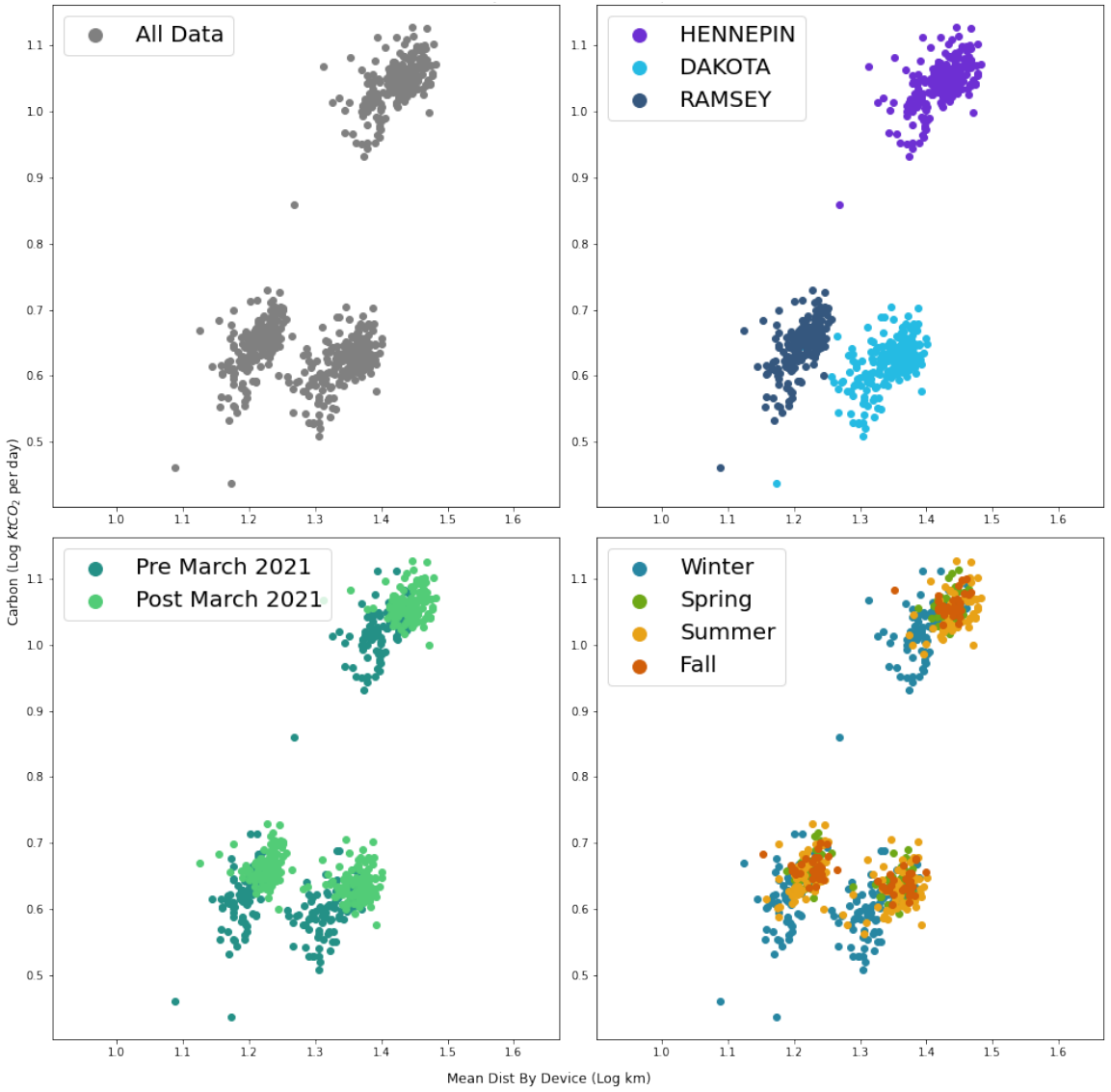


Scaling of Device Distance & Ground Transport Emissions



Ricker Model Expanded

- Sensitivity to binwidth

Illustration of Binwidths