Remote Sensing for Social and Behavioral Sciences

Future Directions for Social and Behavioral Science Methodologies in the Next Decade: A Workshop

Budhu Bhaduri

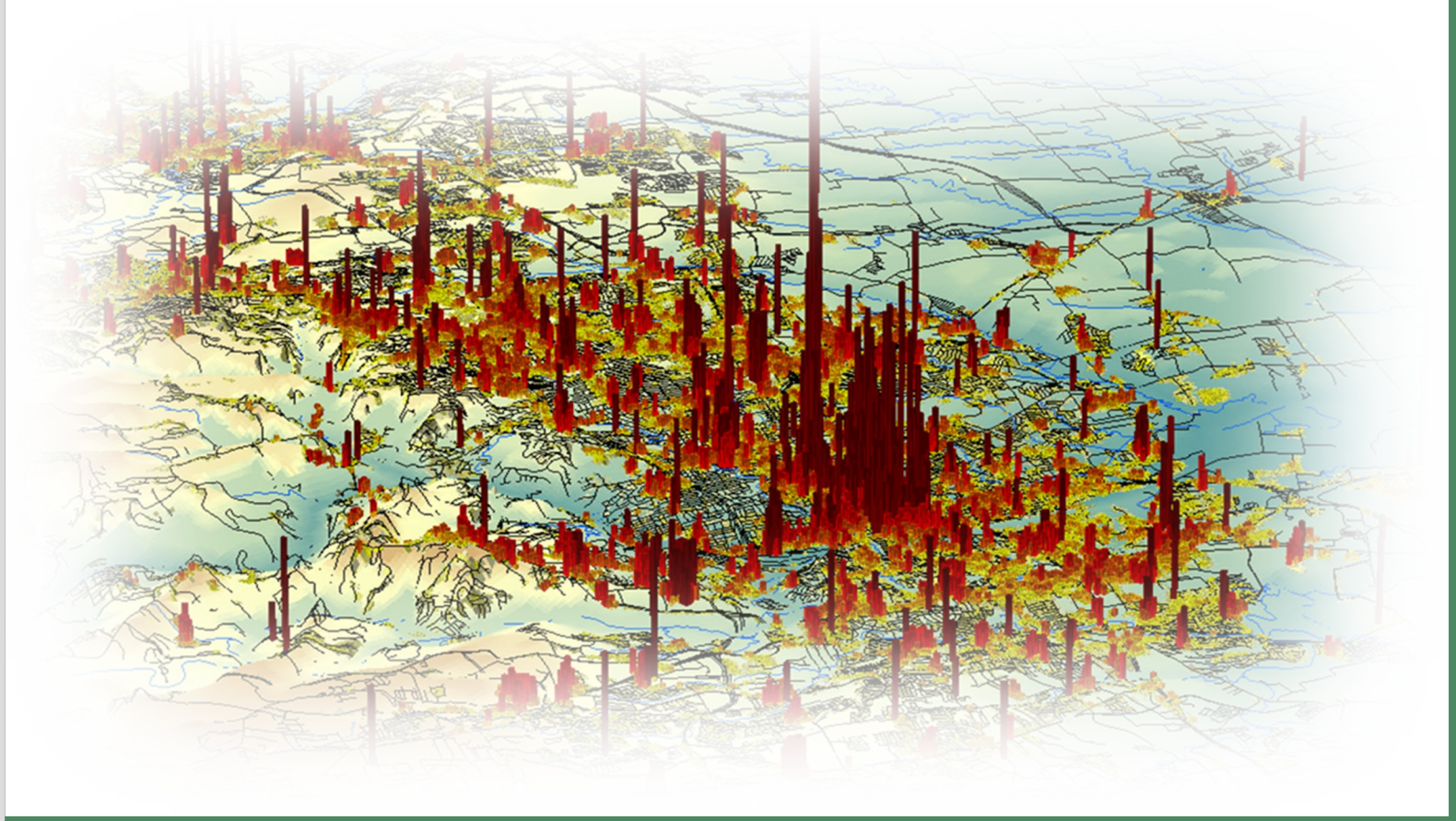
September 26, 2024

Washington, DC

ORNL is managed by UT-Battelle LLC for the US Department of Energy

Overview

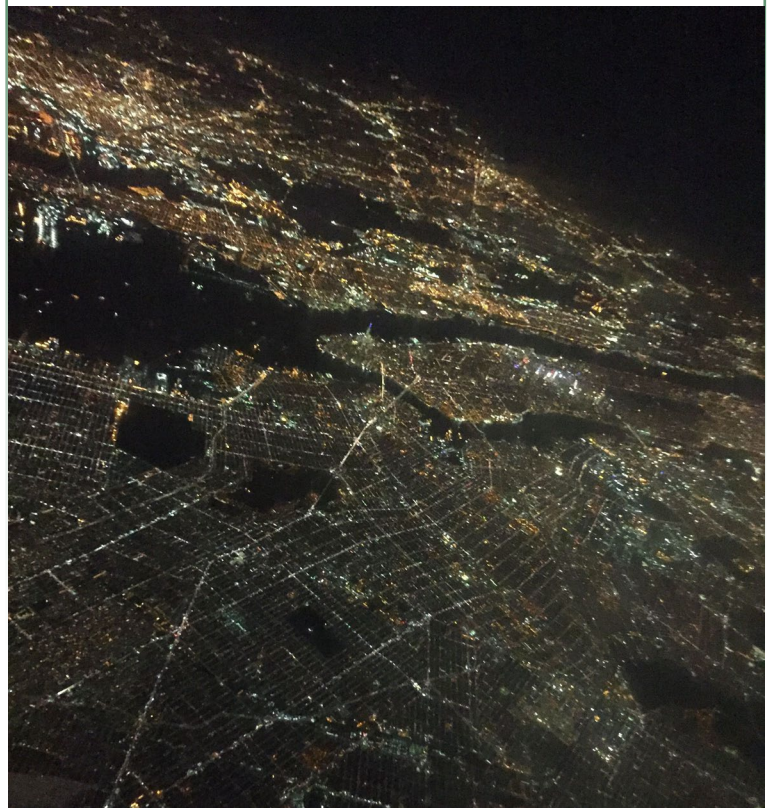
- Defining remote sensing
- People from pixels
- Socioeconomic assessments with remote sensing
- Opportunities and challenges



Remotely sensed observation and measurement data

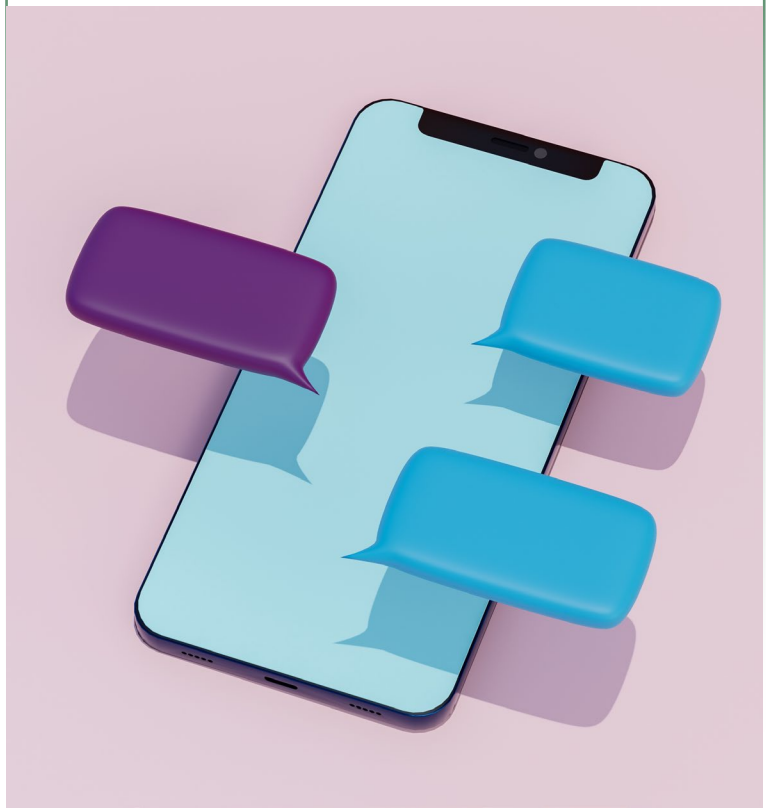
Space and Aerial

- Satellites, aircrafts, drones



Digital Exhaust

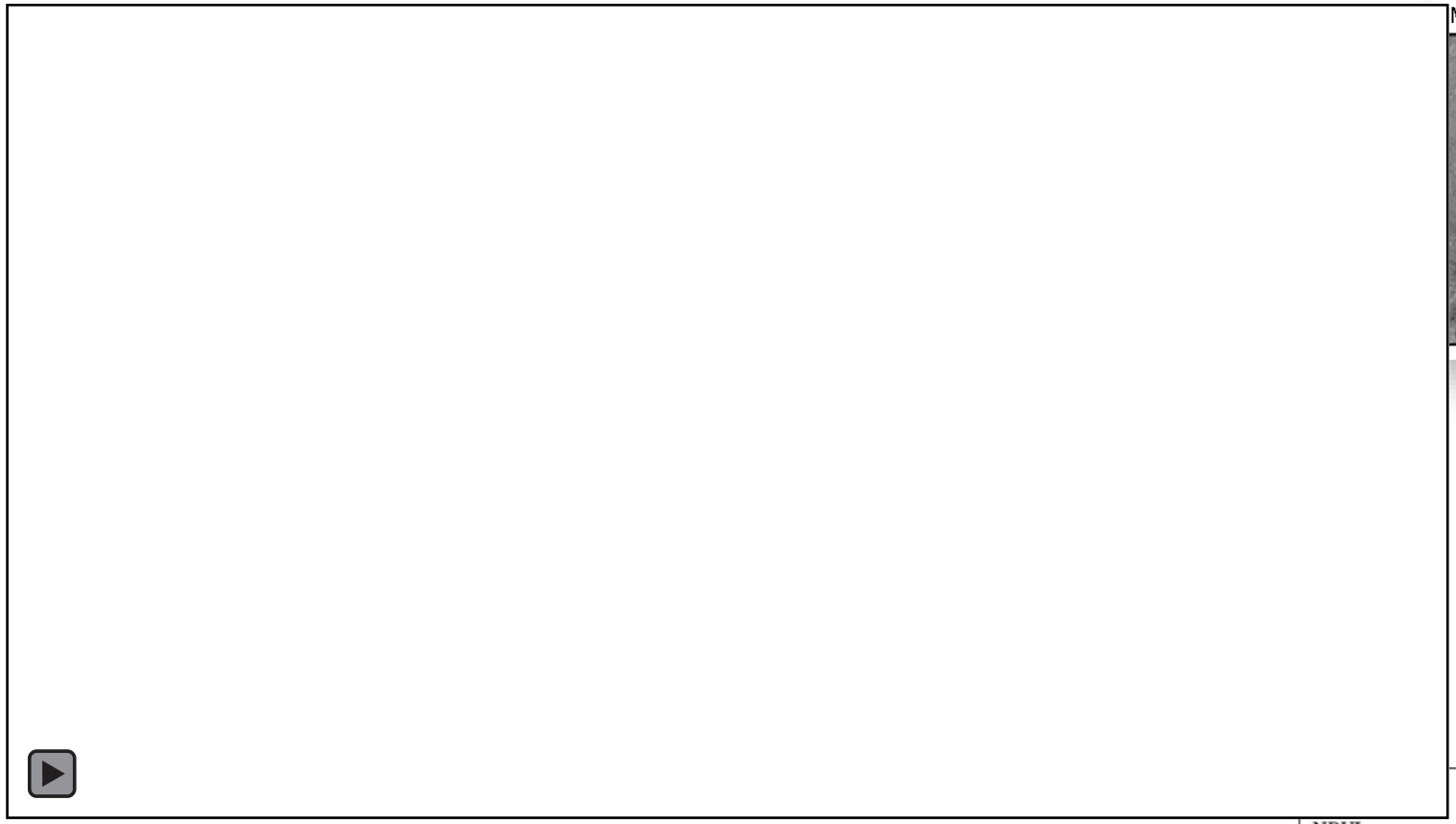
- Social media

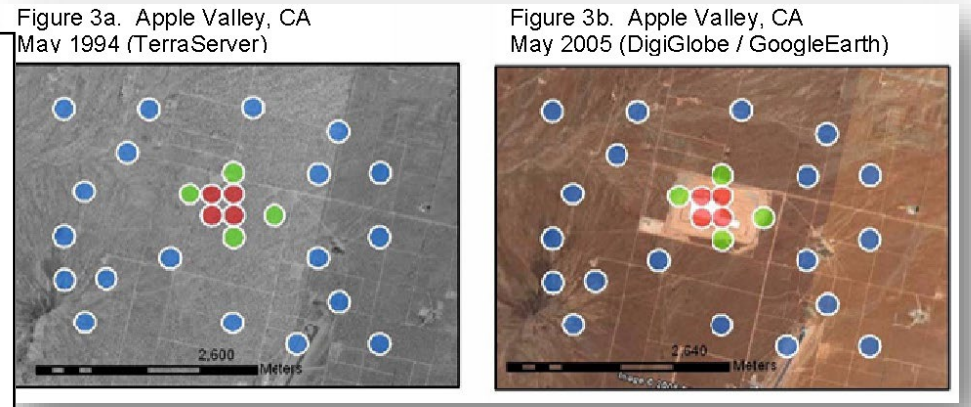


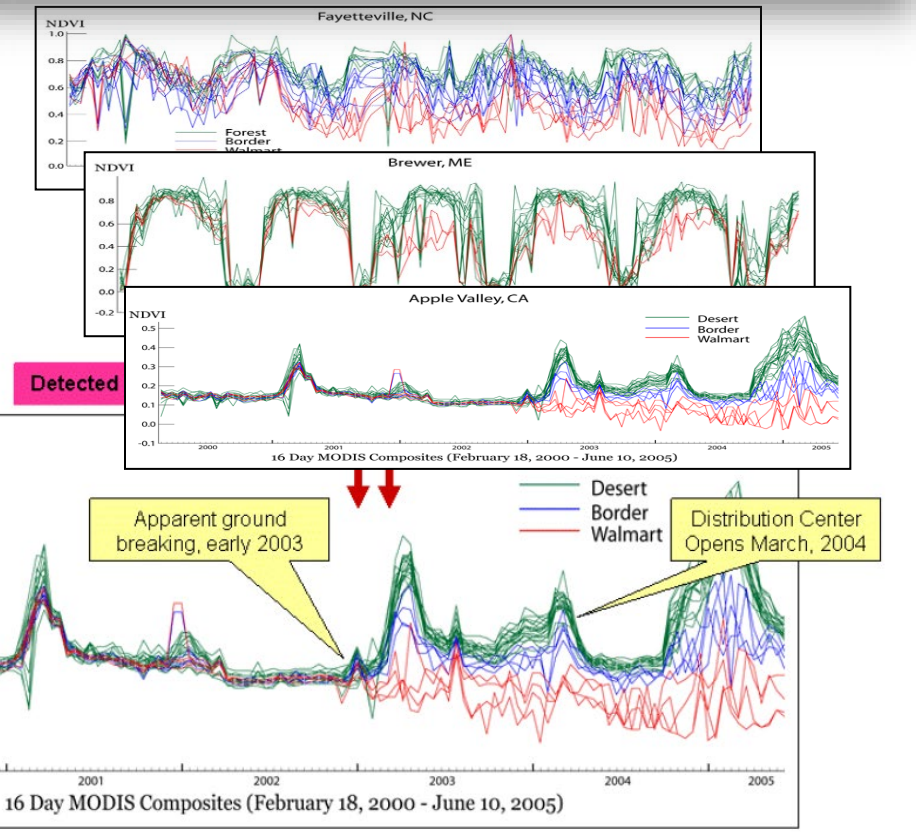
Instrumentation Network

- Smart everything networks

Monitoring changes in the environment



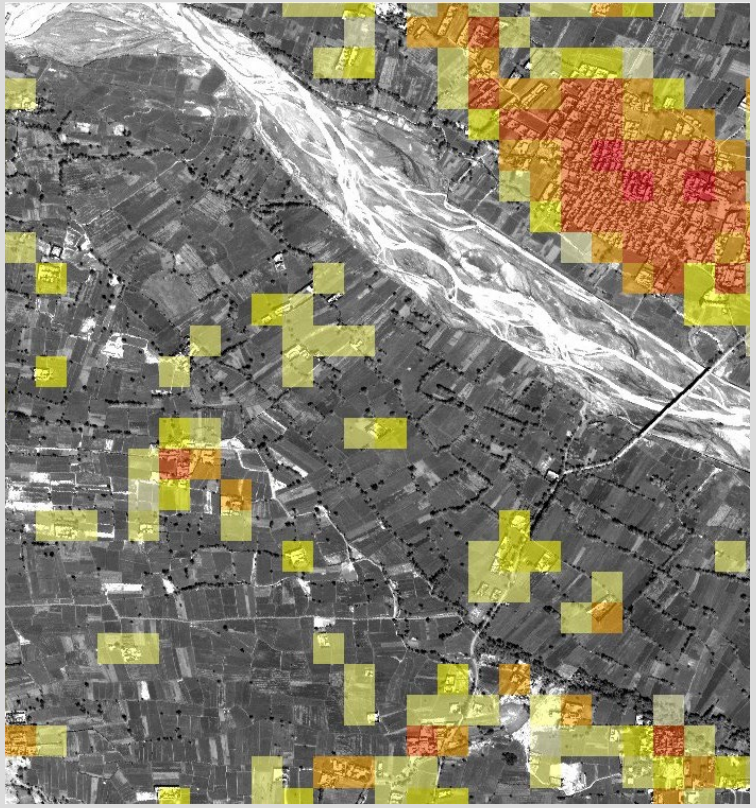




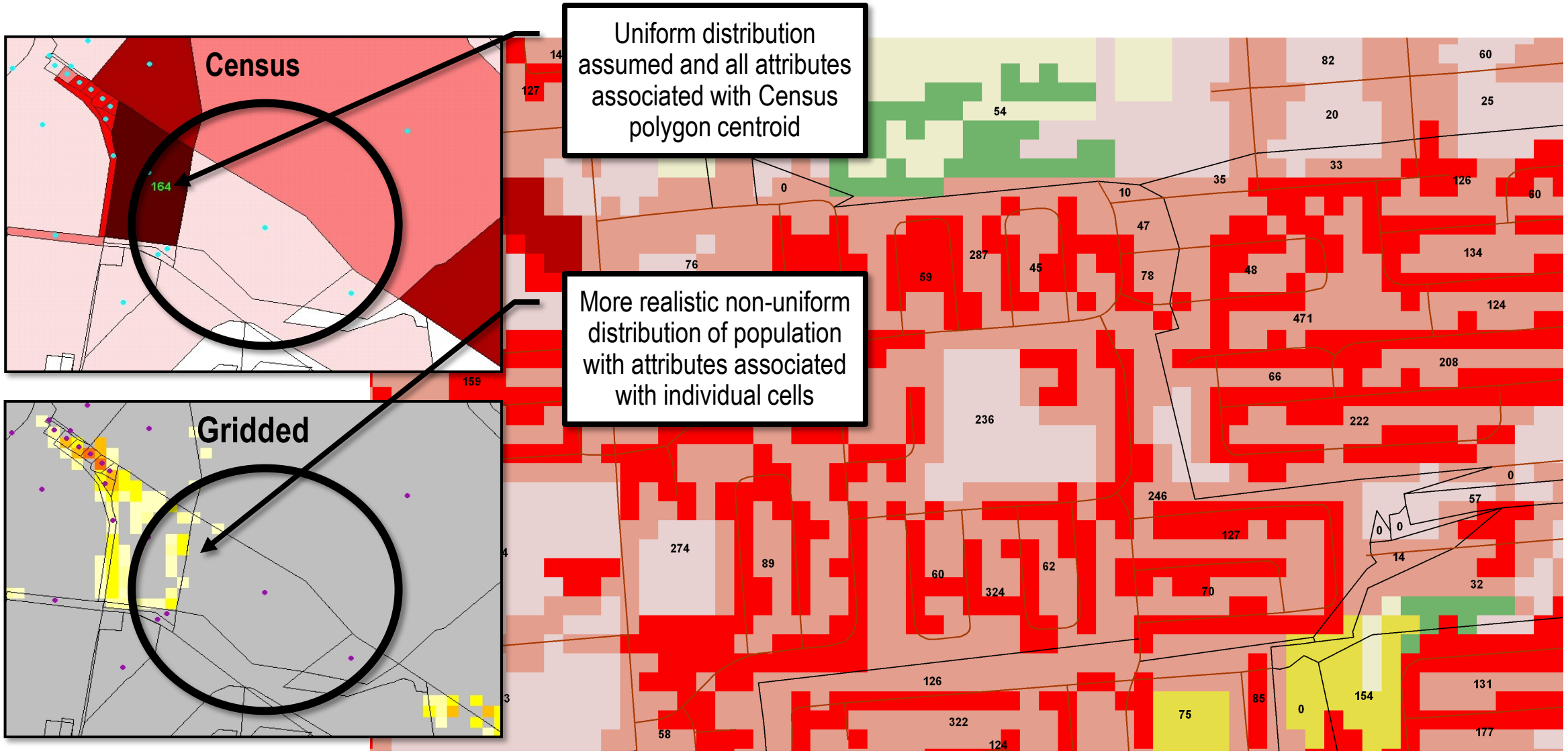
	CA	ME	NC
Alarm	75	52	35
Change Point	70	43	30
Store Opening	93	76	55
Groundbreaking	68	Missing	Missing

Boh[illegible]eierabend, N., Bright, E., Strahler, A. "Walmart from Space: A New Source for Land Co[illegible]nge Validation" Photogrametric Engineering and Remote Sensing. Vol 74. July 2008.

People from Pixels

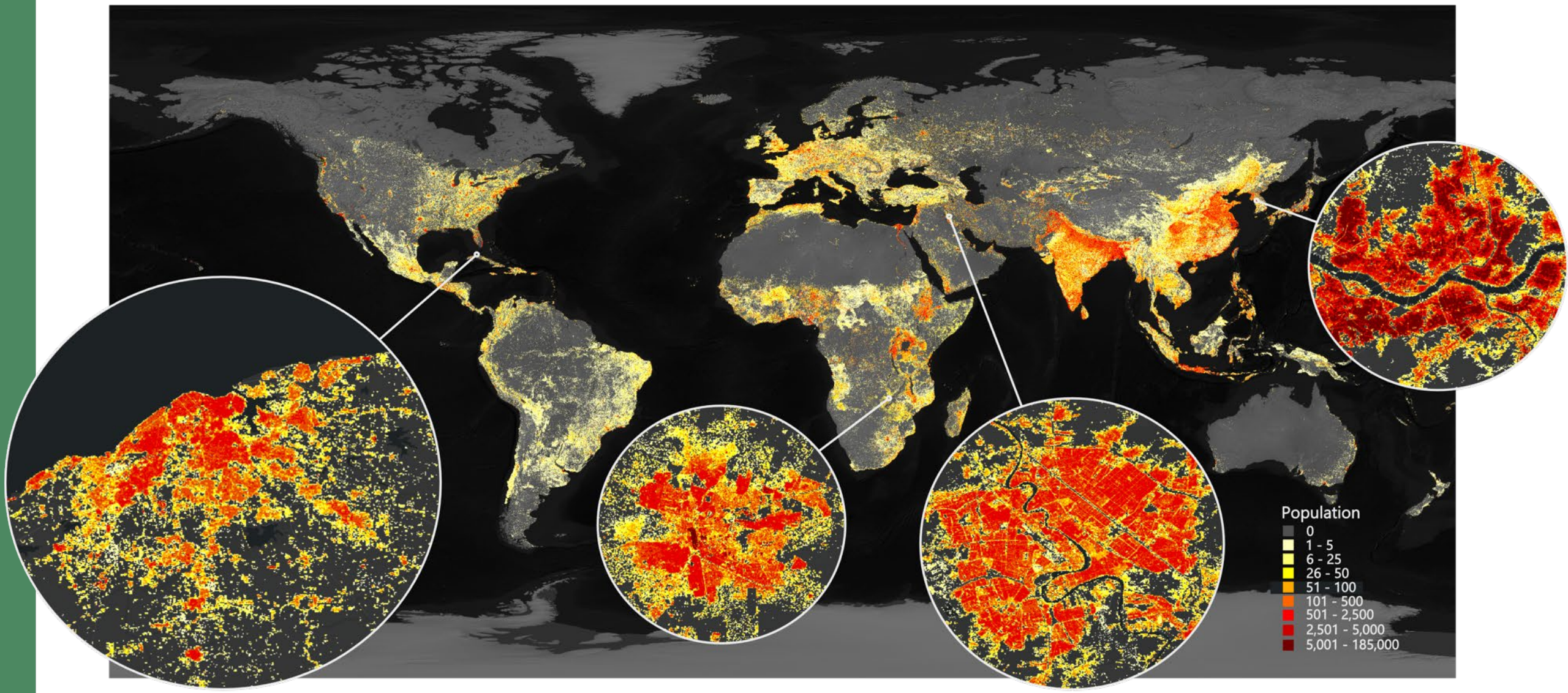


Assessing population at risk needs refinement of Census



OAK RIDGE National Laboratory | 80

LandScan population data for a global community



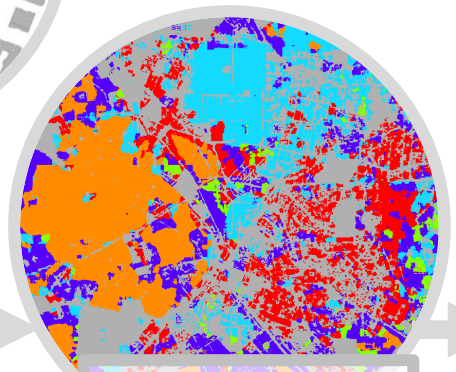
OAK RIDGE National Laboratory | 80

LandScan HD: 90m global population

Building outlines

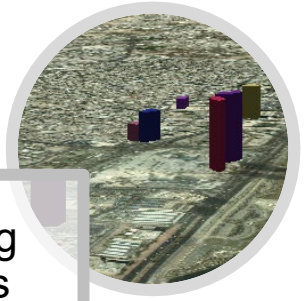
High-resolution imagery (multi-spectral, panchromatic)

Settlement area



Neighborhood mapping/Settlement density (automated building counts,)

Building heights (DEM/LiDAR, Google StreetView)



Land use via open source data/VGI (Wikimapia, zoning data)

Population density (DHS, PDT, Census, Micro-Census)

OAK RIDGE National Laboratory

USA Structures

Mapping US Buildings at Scale

FEMA

Goal

- Develop machine learning (ML) model to automatically map building footprints from high-resolution satellite imagery for the US
- Process 1.2 petabytes of raw imagery data

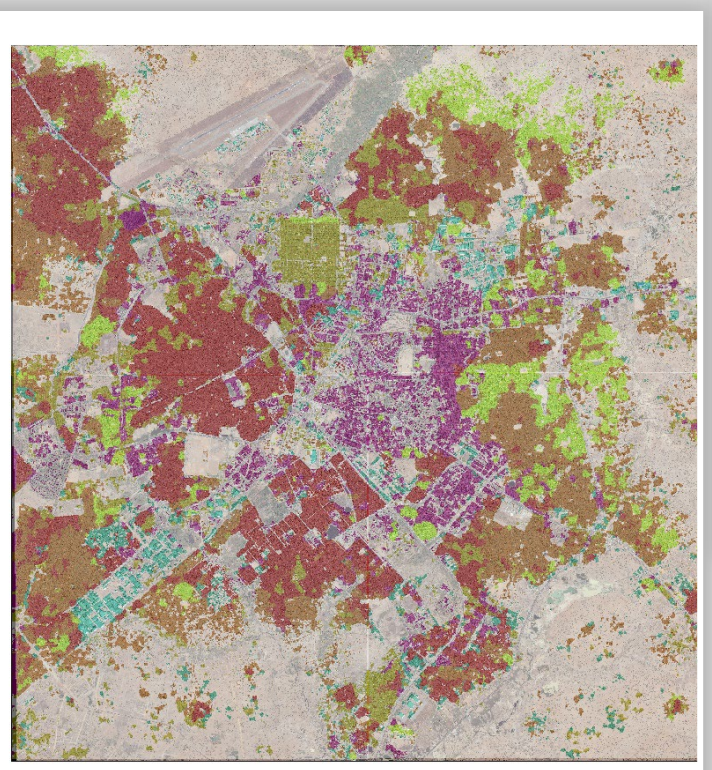
Scale Model to US

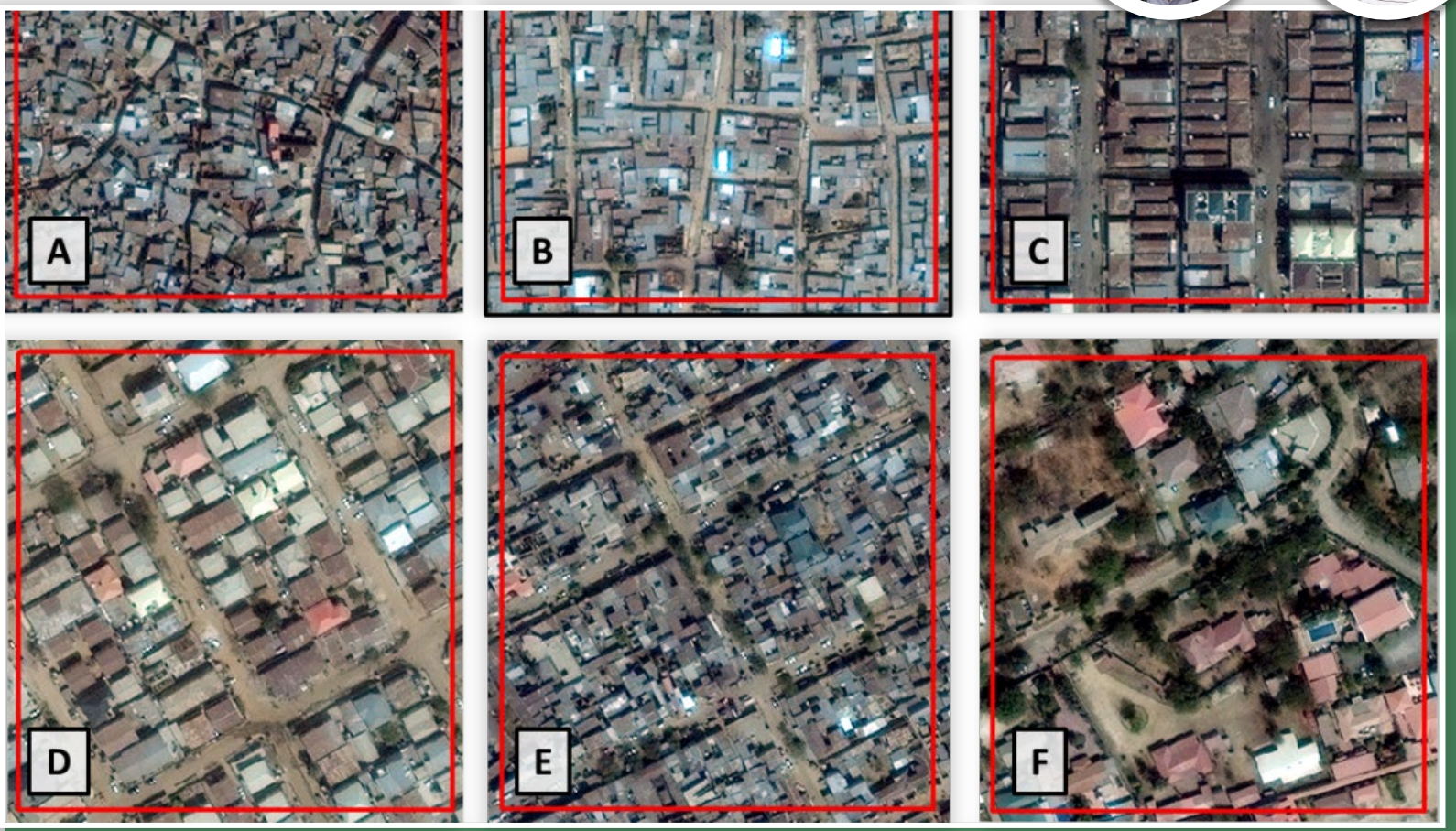
- 3% of US consists of buildings
- Improve the model to work across new geographies to enable US-wide autonomous mapping of structures

Enrich Buildings with Mission-Relevant Attribution

- Continually improve the ML model with new training data, develop new models that apply ML to add attribution, and enhance attribution through multi-source conflation

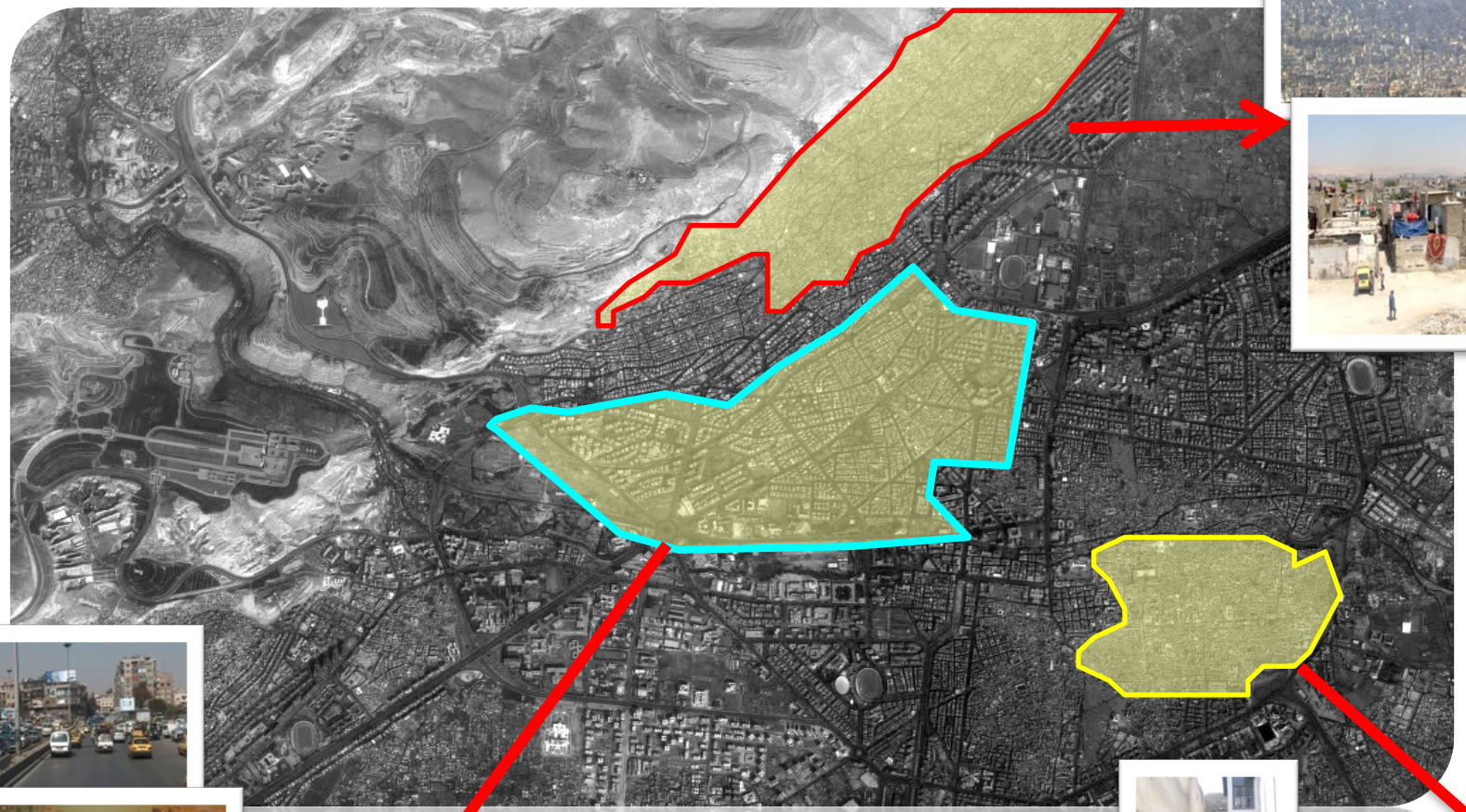
Neighborhood Mapping



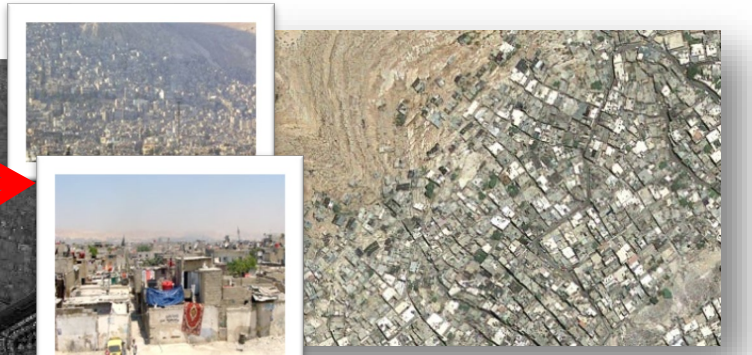


Courtesy: Jake Arndt, Dalton Lunga

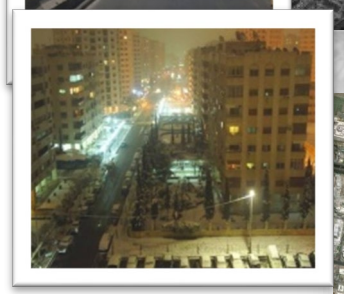
Settlement patterns are socioeconomic indicators

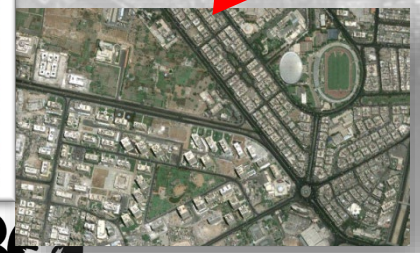


Damascus, Syria

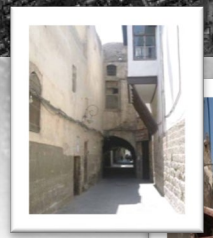


- Unstructured Settlements
- Lowest to lower middle income
- Rural migrants





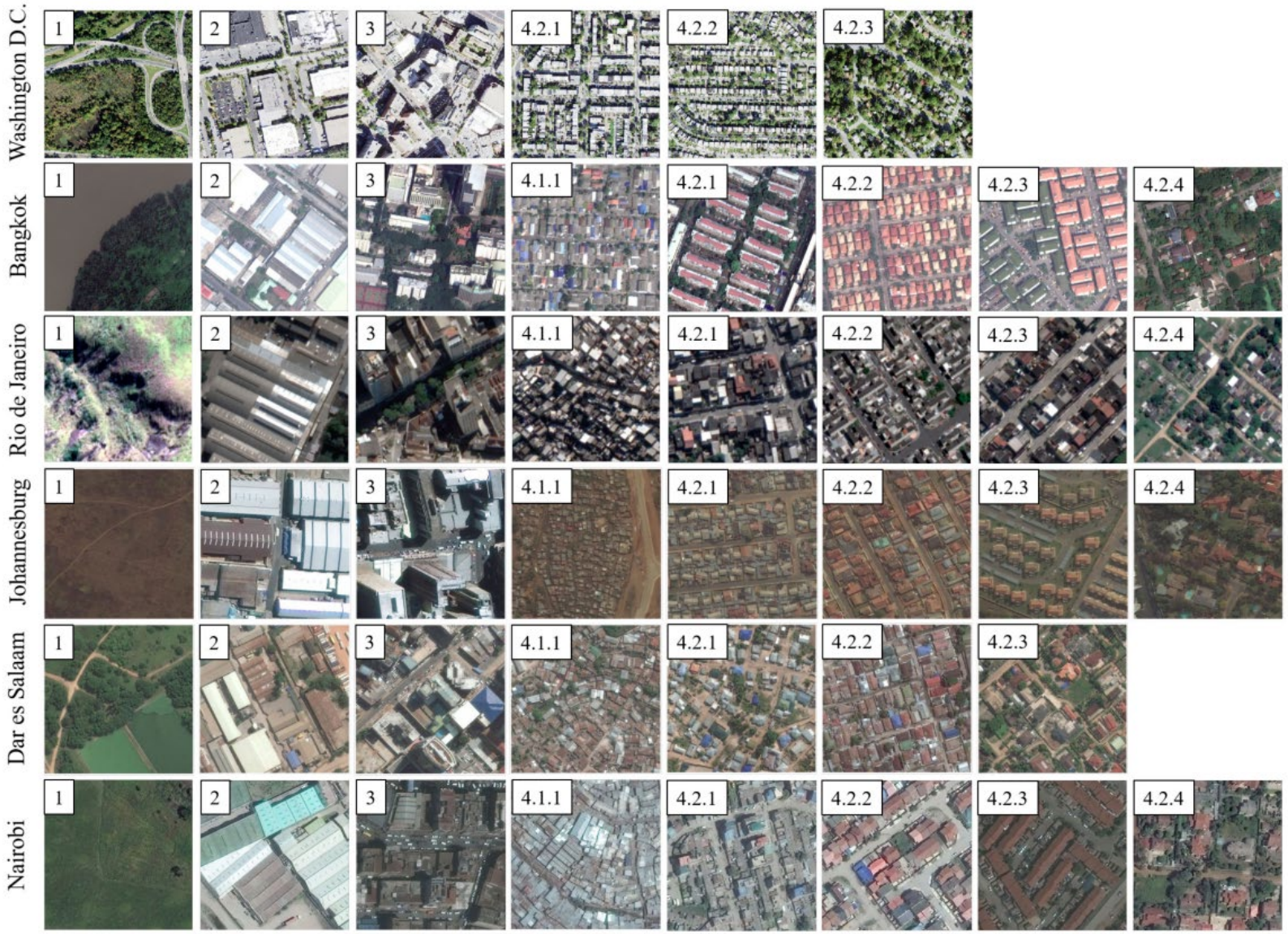
- Formal Urban Planning
- Typical Urban Services
- Middle to Upper Income



- Very loosely structured
- Historical ethnic quarters/neighborhoods

Identifying Neighborhood Types Using Visual Indicators

- Taxonomies
  - Defining which categories to map
  - Image interpretation and analysis of buildings, roads, and open-space
    - Concepts of urban morphology
- Spatial characteristics
  - **Buildings:** size, height, density, uniformity, arrangement, roof materials
  - **Roads:** access, width, surface type, arrangement
  - **Open space:** plot size, green-space, position of building on plot

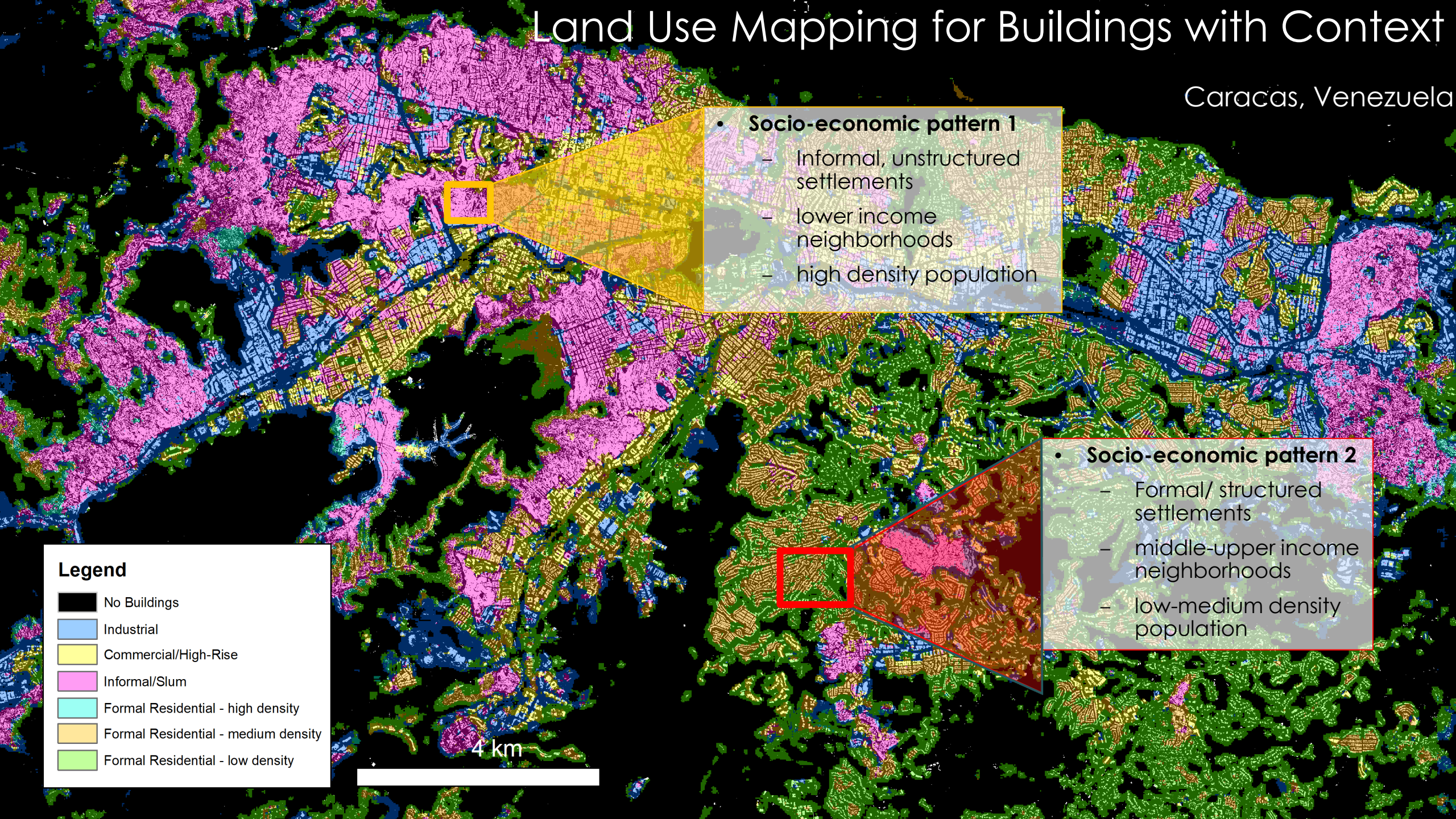



Caracas, Venezuela
4 km


Building Footprints
Caracas, Venezuela
4 km

Land Use Mapping for Buildings with Context

Caracas, Venezuela



Deprived Area Mapping

- Identifying deprived areas is a foundational step in monitoring progress towards SDG target 11.1
- Current estimates of people living in deprived areas is highly uncertain
  - Studies suggest they are largely underestimated
- We are currently working on adapting these models and workflow for identifying and understanding deprived areas

sdgs.un.org/goals

Figure 1. Inference results in Mumbai for October 2023

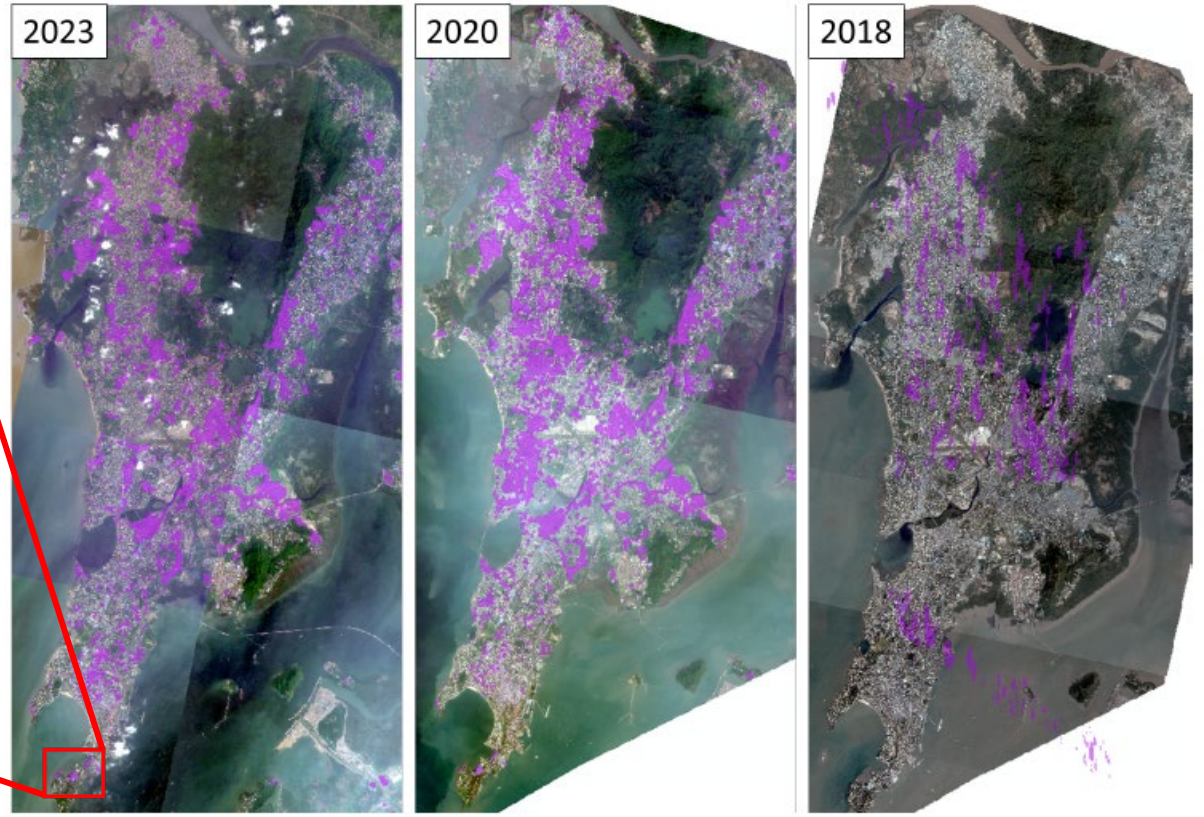
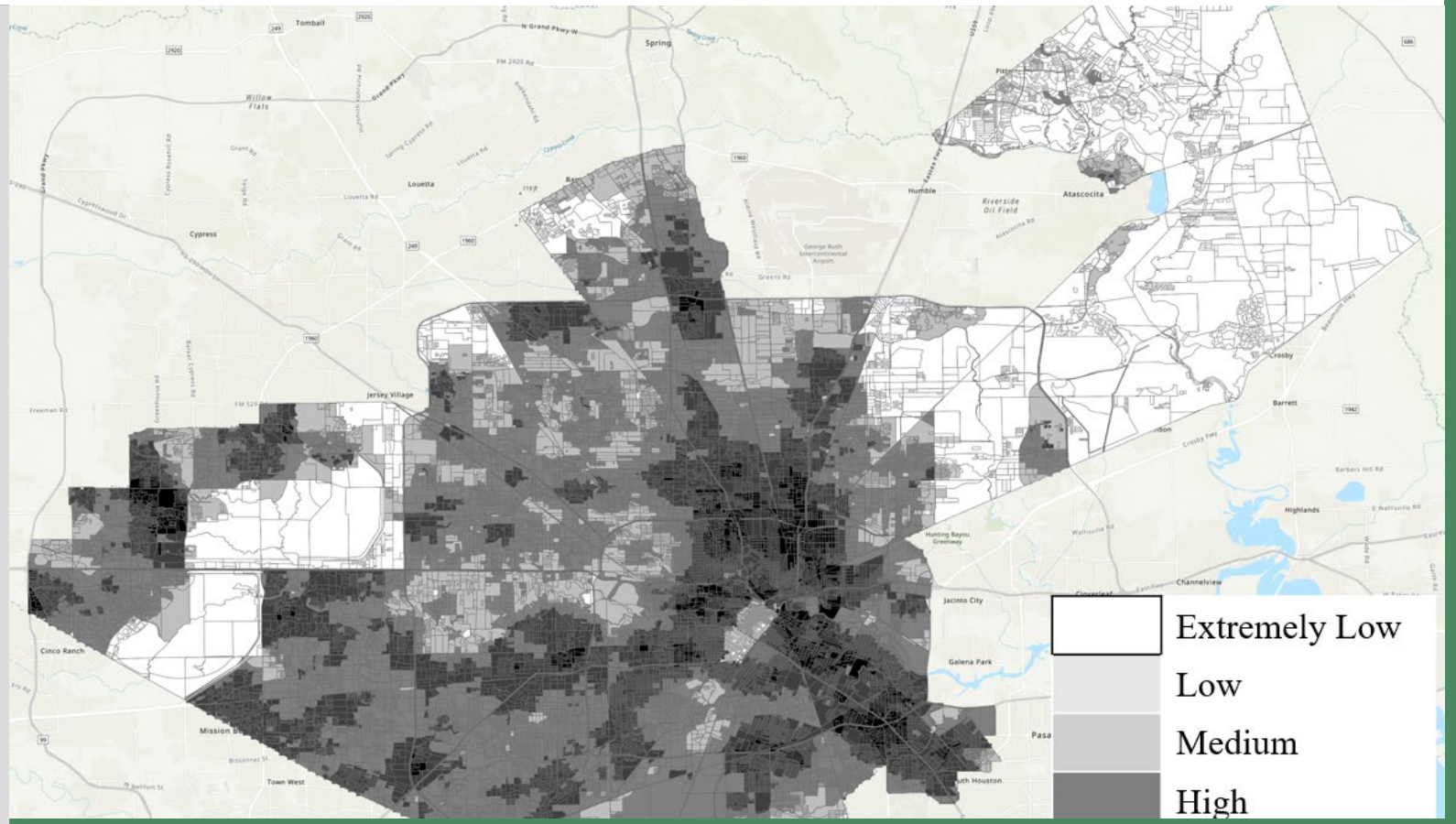


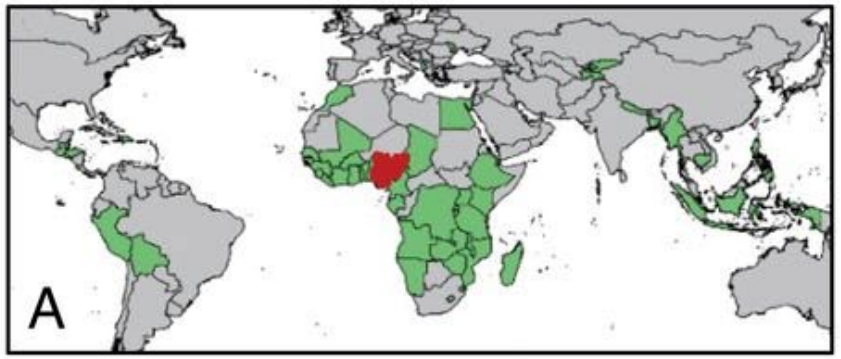
Figure 2. Inference results in Mumbai for 2023, 2020 and 2018

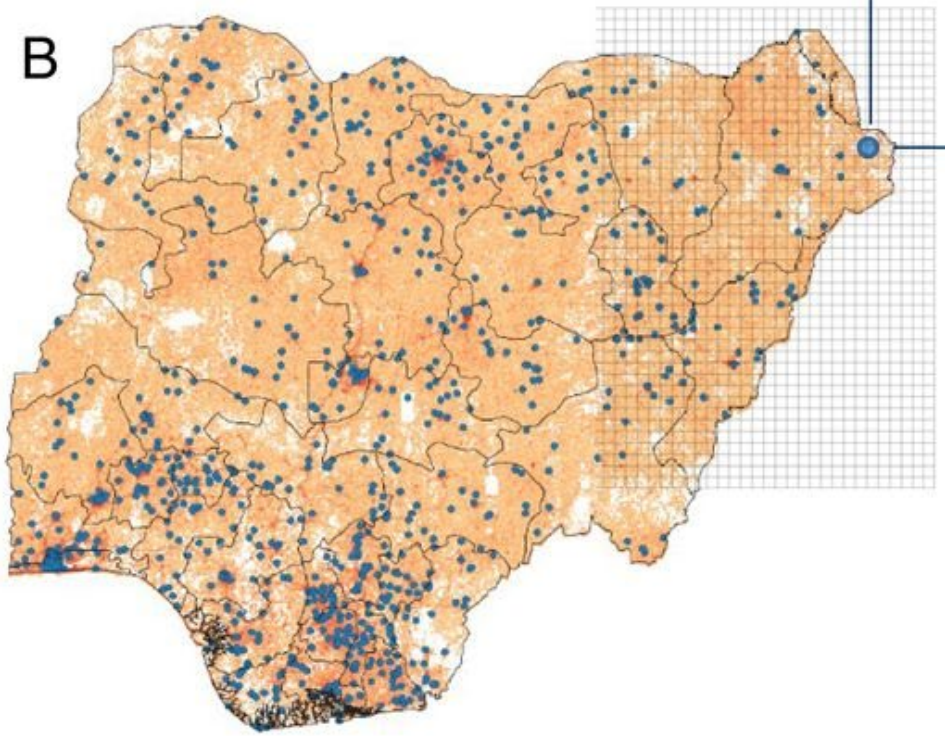
Applications

- Wealth Index
- Energy Justice
- Patterns of Life



Relative Wealth Index





GROUND TRUTH DATA

- Villages with surveys
- 20-50 surveys per village
- 2-4 hours per survey

GEOSPATIAL "BIG" DATA

- **Satellites**
  High-res imagery, night lights
- **Connectivity**
  Cell towers, devices
- **Demography**
  Population
- **Geography**
  Road density, elevation

MACHINE LEARNING

C

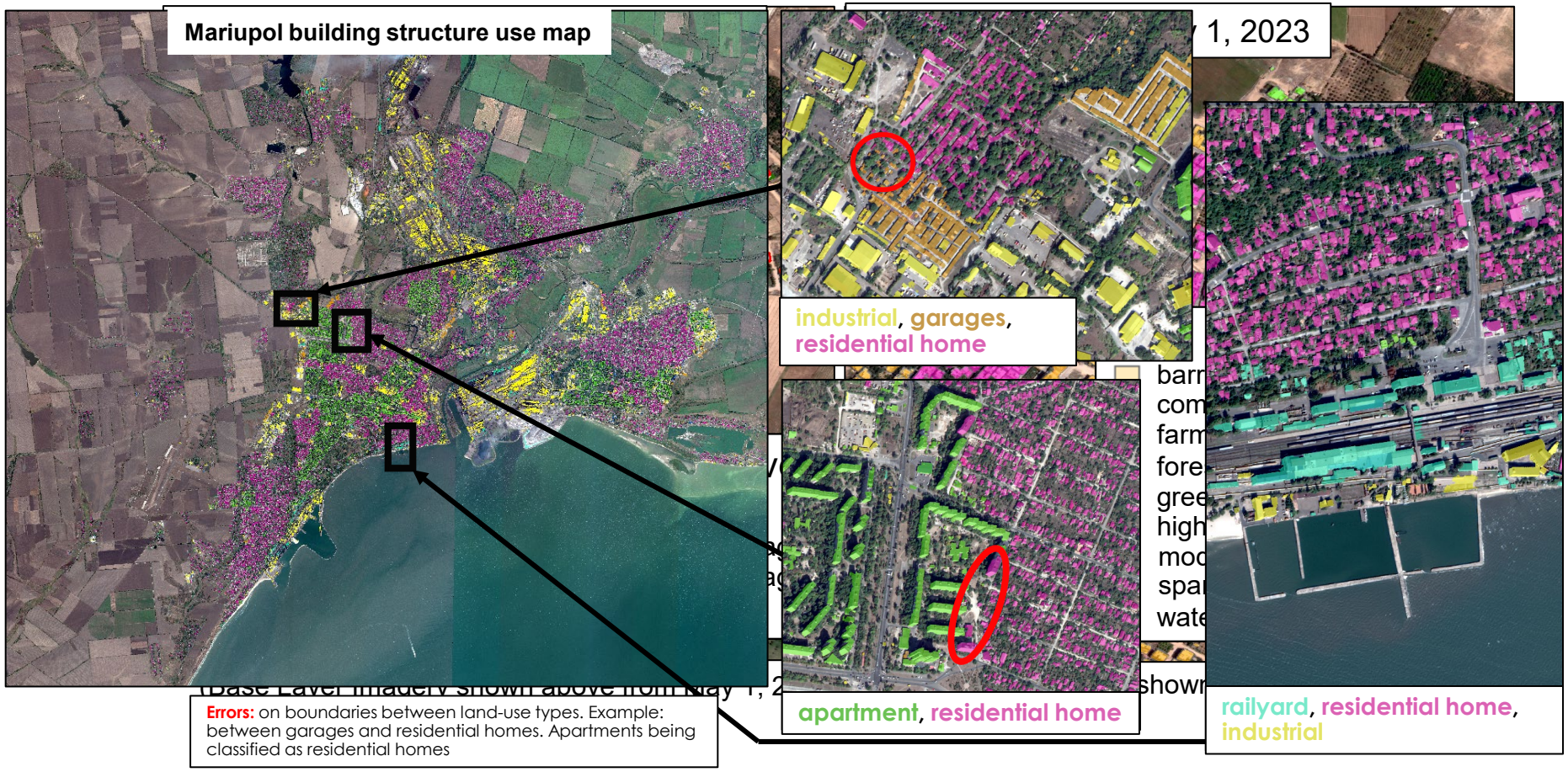
Chi et al. (2022), PNAS, https://doi.org/10.1073/pnas.21136581

Building Damage Assessment and Neighborhoods

- Armed conflict in Ukraine and Gaza
- Damage assessment by infrastructure type / built form
- Neighborhood mapping workflow and model training is easily adapted to different categories
- For this application, we consider land-use land-cover categories

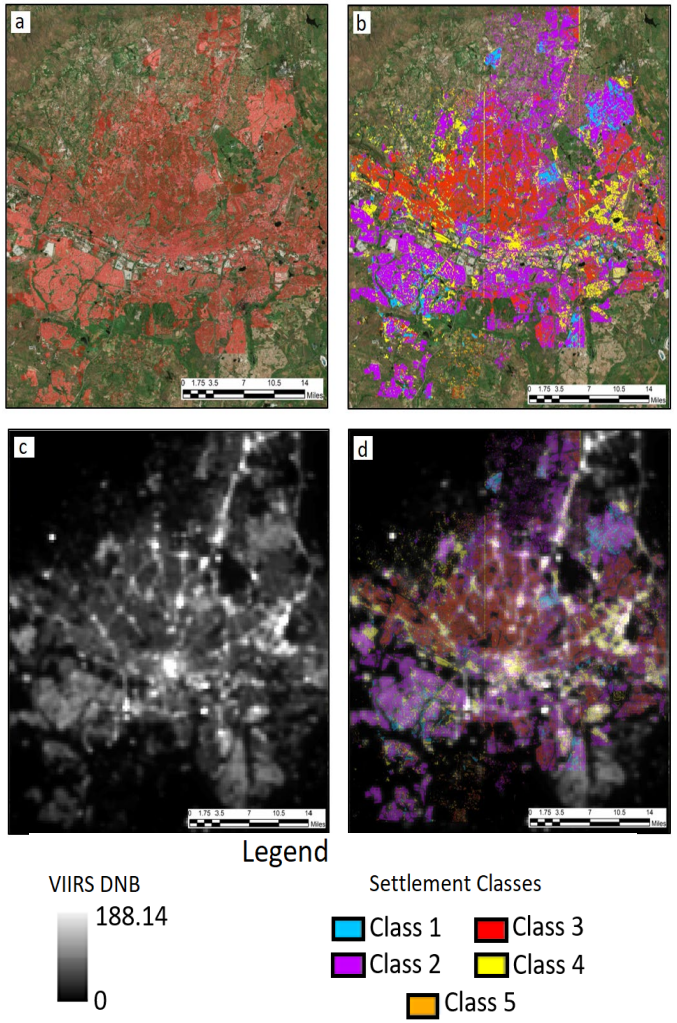
Land-use attribution over Mariupol, Ukraine

Conflated with pre-event building detection dataset



OAK RIDGE National Laboratory

Data driven settlement characterization in assessing intra-urban electricity consumption patterns



- Three cities Ndola, Zambia; Sana'a, Yemen; and Johannesburg, South Africa were selected for the exercise.
- Gabor and LoG filters were applied to capture spatial characteristics of human settlements.
- The settlement inventory was classified into five broad and generalizable classes with probable socio-economic implications.
- To meet the scarcity of electricity data, 2015 annual VIIRS nighttime lights composite was used as a proxy.
- Relationship between VIIRS light values and corresponding proportion of settlement types were then assessed.

$$DN_{VIIRSDNB} = (\sum_{i=1}^{5} \beta_i * Settlement_i) + \varepsilon$$

Johannesburg: $R^2 = 0.44$ ($F(5,13954) = 2166$, $p < 0.0001$)

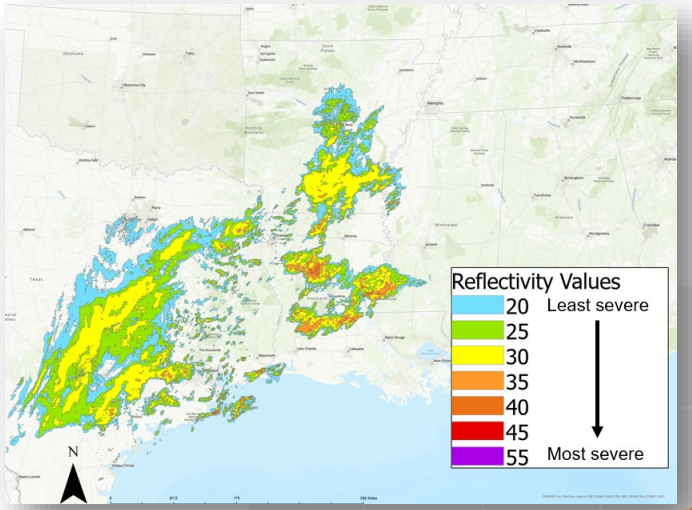
Sana'a: $R^2 = 0.61$ ($F(5,2024) = 633.6$, $p < 0.0001$)

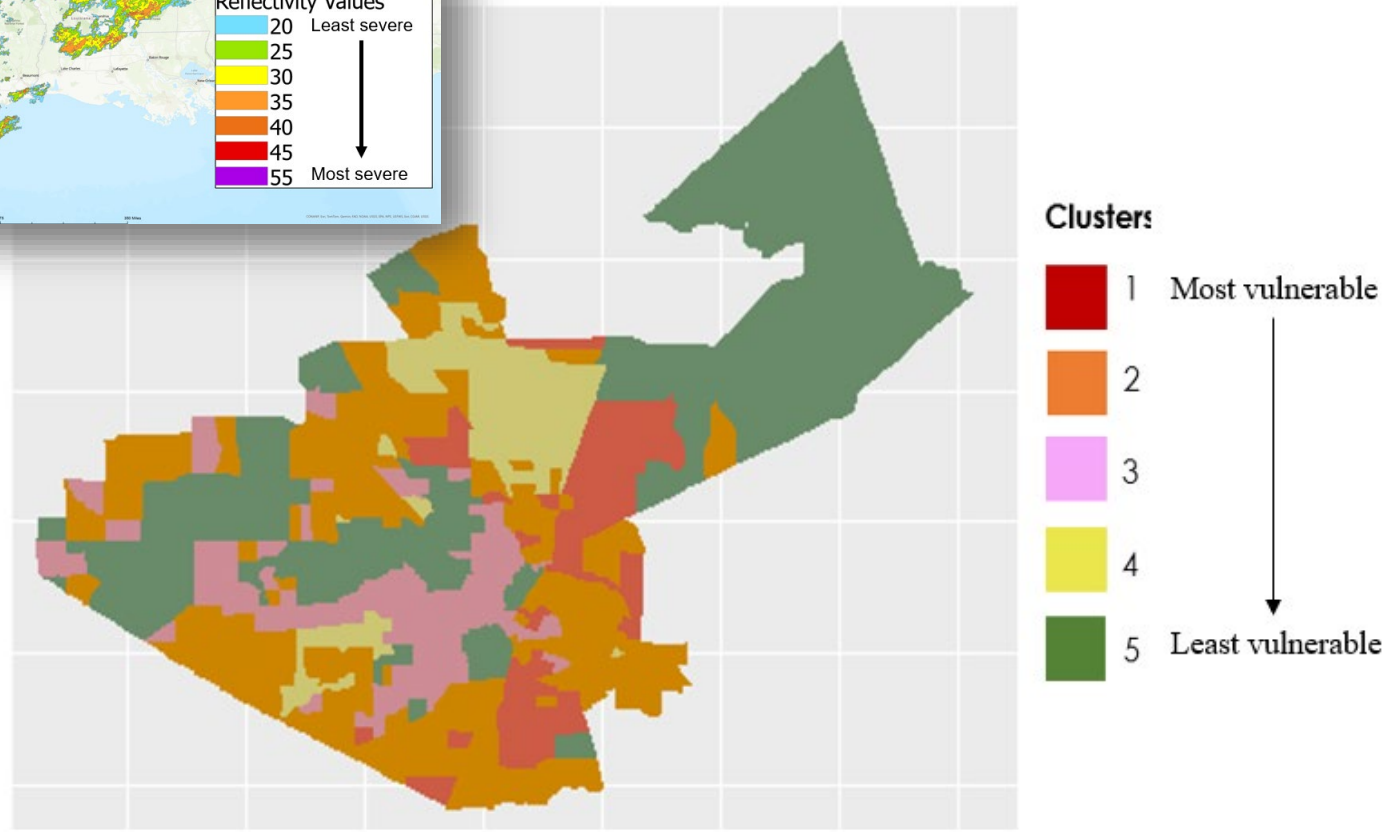
Ndola: $R^2 = 0.73$ ($F(5,999) = 532.1$, $p < 0.0001$)

Roy Chowdhury et al. 2019. https://doi.org/10.1080/17538947.2018.1556355

Inequal Outage Vulnerability at Census Tract Scale

- High income areas with higher tree coverage and buried utilities have lower likelihood of outages
- Some Tracts have over 80% likelihood of outage
- These tracts show high instances of linguistic isolation, independent living difficulties and poverty
- Tracts with increased prevalence of multiple individual vulnerability profiles tend to face higher likelihood of outages





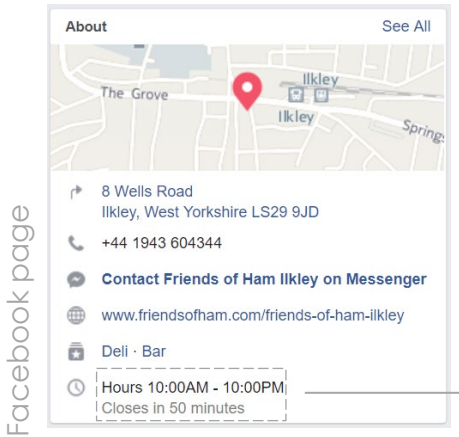
Kahl, A., et al. (2024). *Coupling Outage Likelihood and Synthetic Populations: Energy Justice Recommendations for Houston, TX.* [Manuscript in preparation].

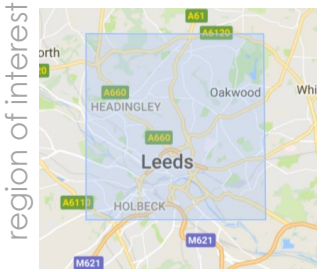
OAK RIDGE National Laboratory | 80

BREDESEN CENTER

Temporal Signatures for Points of Interests' Hours of Operation

global analysis

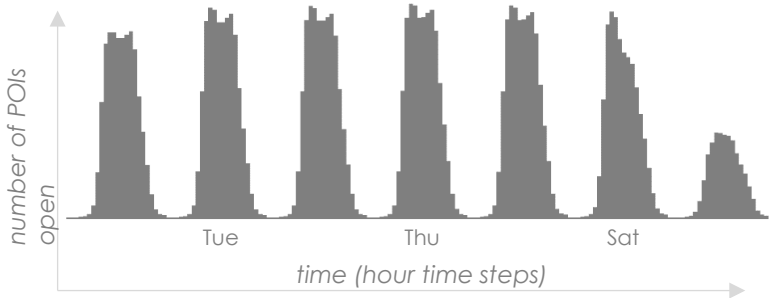




+14 mil POIs globally

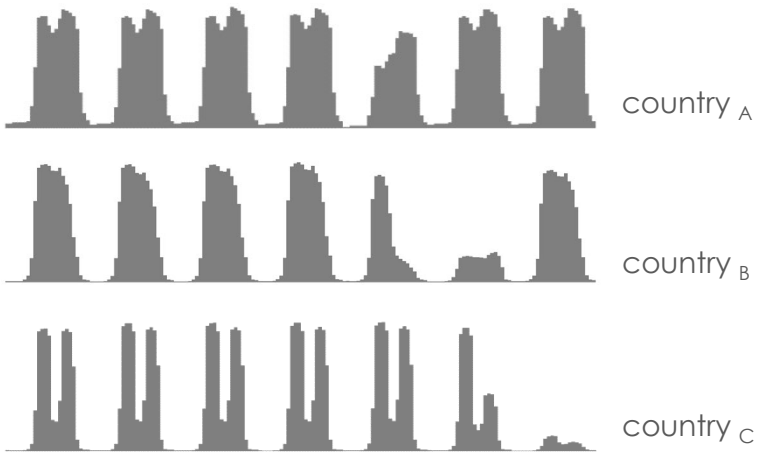
Temporal signature for region of interest

created from all POIs within region



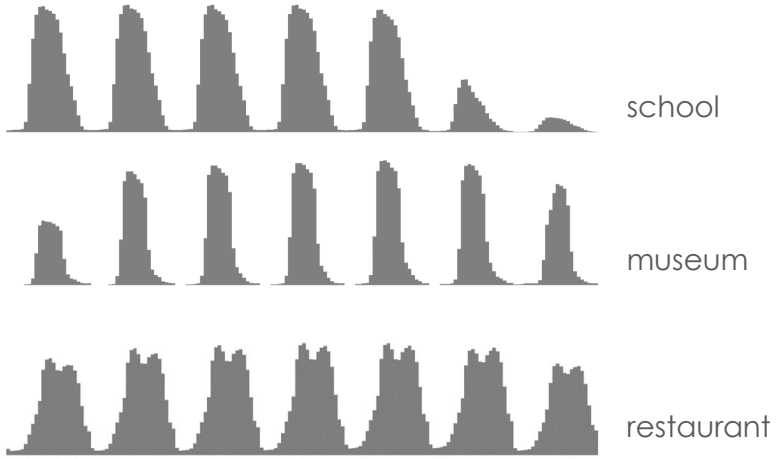
Differences across space

within facility category (e.g. retail)



Differences across facility categories

within space (global)



By studying the hours of operation for various facilities (e.g., restaurants, museums, retail, etc.) around the world, we can improve our understanding of the fundamental cultural and regional effects that shape the dynamics of human societies at an aggregate scale.

OUTPUT

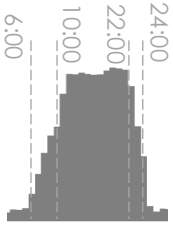
Understand the external processes that drive the patterns we see in signatures

Honduras
97% Catholic

Kuwait
76% Muslim

Religion
Temperature
Colonialism
…

Automatically generate temporal population transition periods

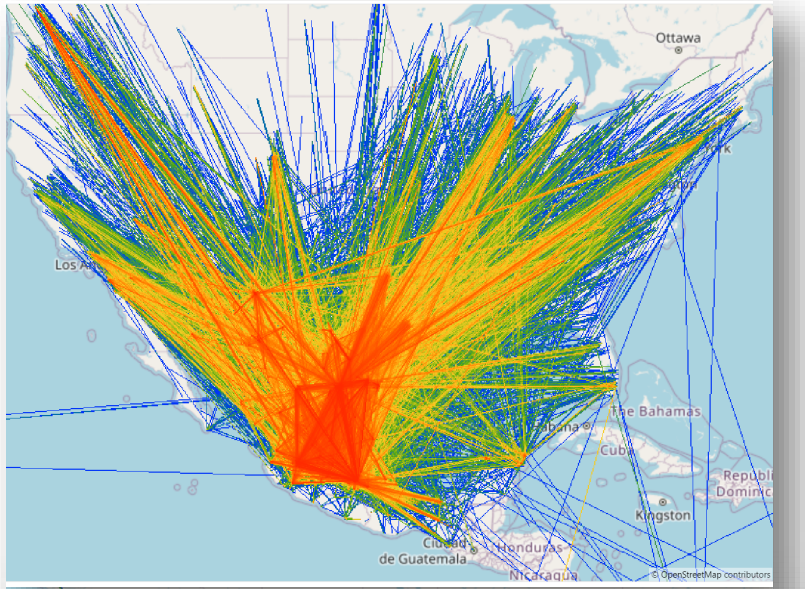


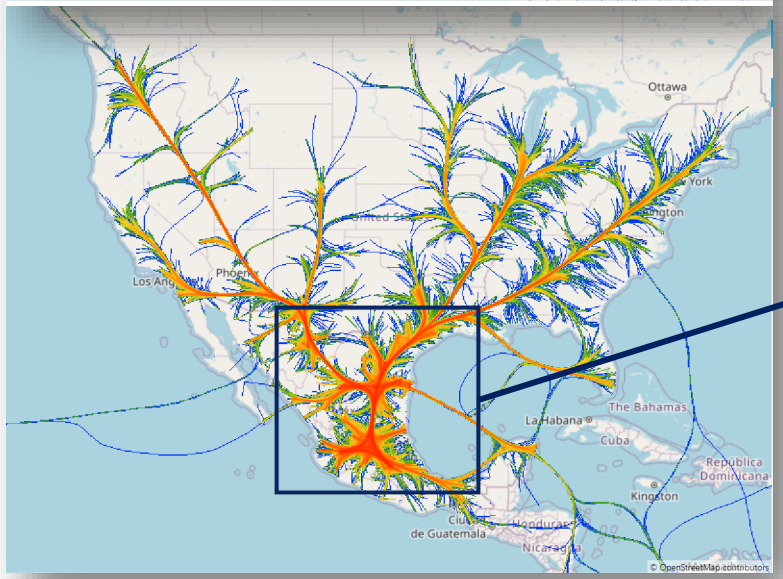
Morning
Day
Evening
Night

OAK RIDGE National Laboratory | 80

Opportunities and Challenges

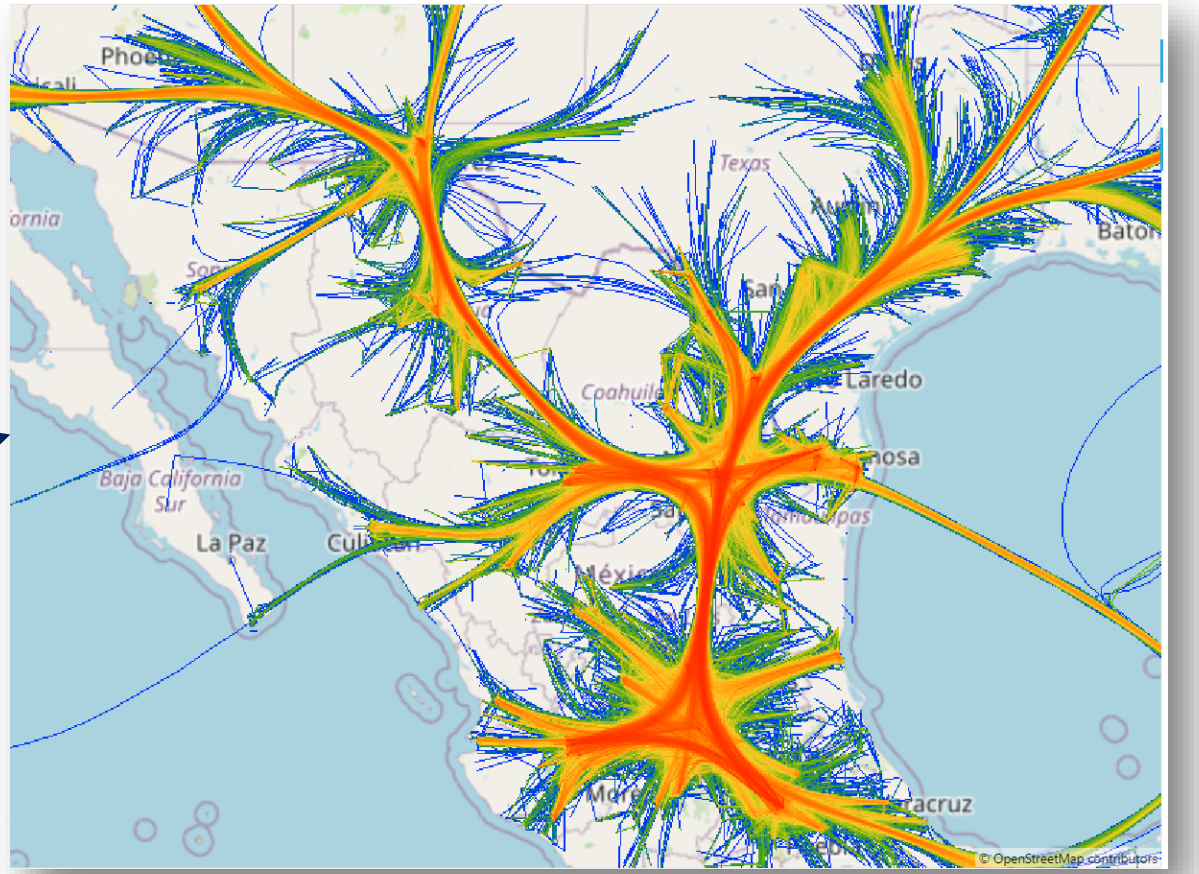
Hubs, Choke Points, and Movement Flows





Major flow corridor between Mexico City and Monterrey

Major flow destinations in the US include cities in California, Washington, Colorado, Texas, Illinois, New York, Florida, etc.

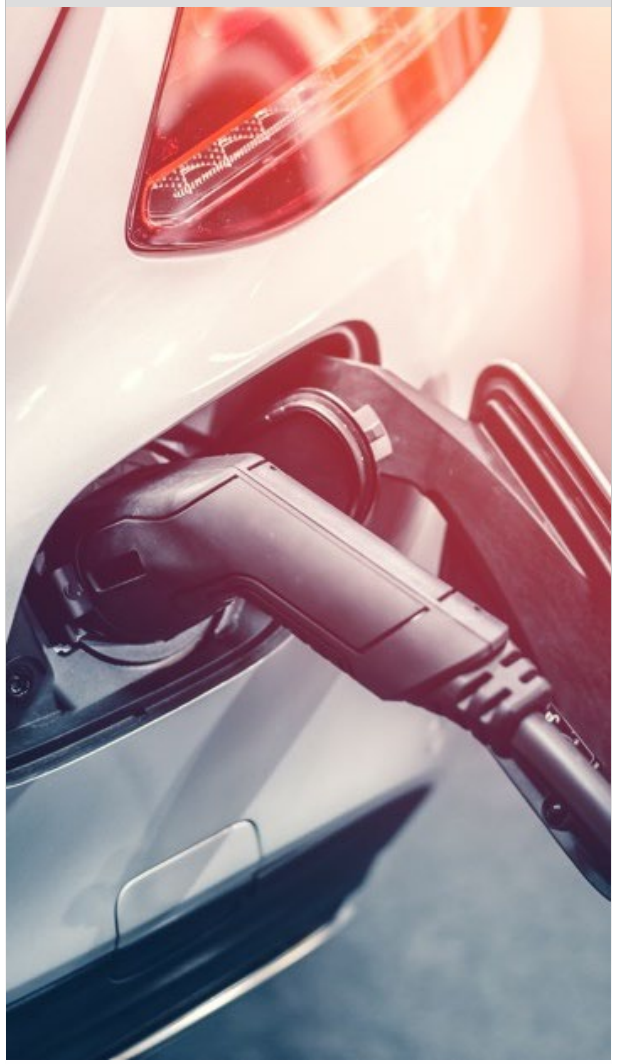


Courtesy: Junchuan Fan

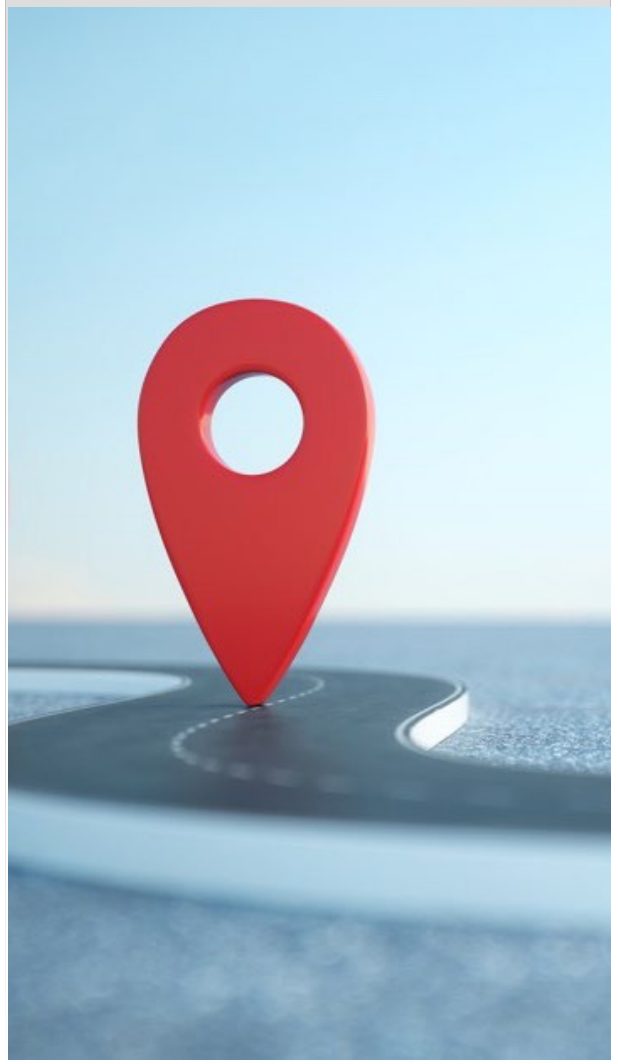
Future with remote sensing

- Satellites for social science?
- Social processes and higher temporal resolution of data
- Human response to environmental changes
- Will society see an open data economy?

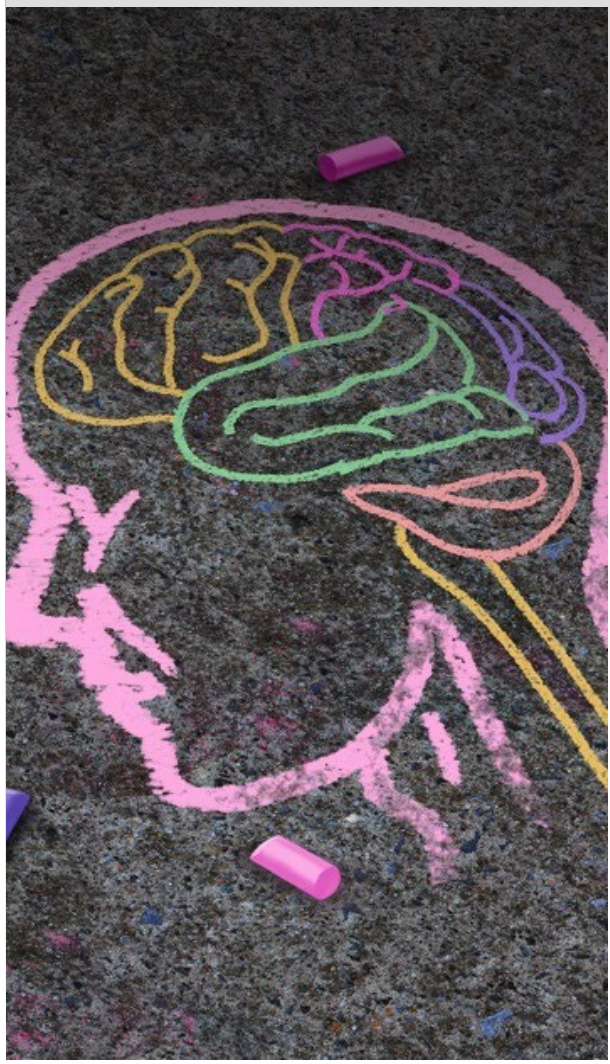
Consumer Behavior



Activity Trails



Health and Biometric



DISCUSSION

OAK RIDGE National Laboratory