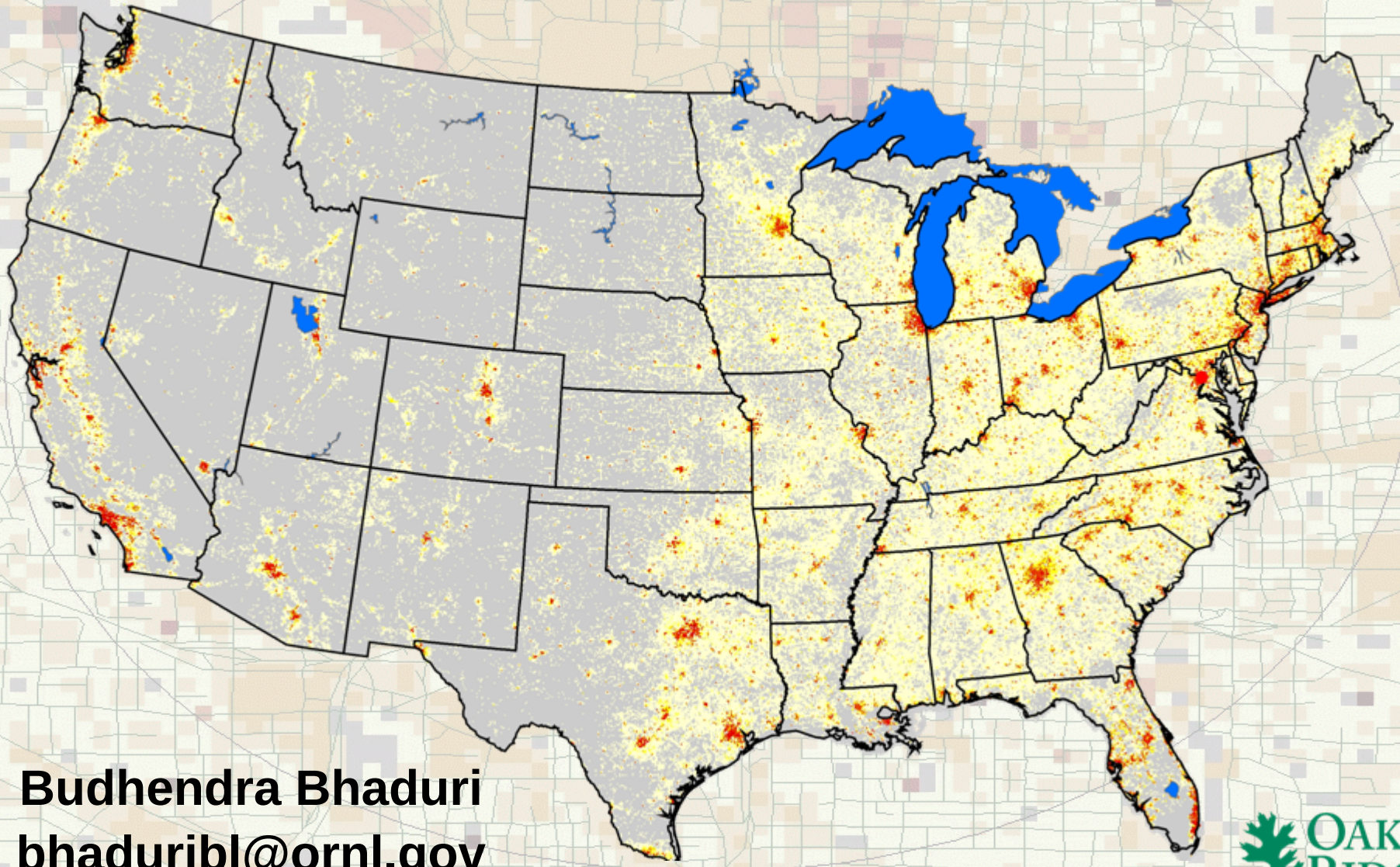
Geospatial Modeling and Simulation of Population Dynamics



Budhendra Bhaduri
bhaduribl@ornl.gov

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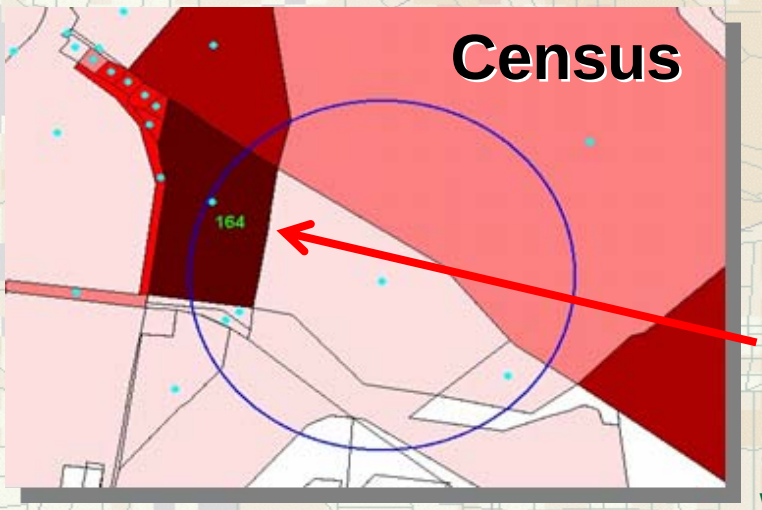
Overview

- **Introduction and Background**
  - Disaggregation of Census data
- **LandScan: Population Distribution Model**
- **Computational approaches**
  - Input data refinement, alignment, integration
  - Modeling framework
  - Verification and validation
- **Applications**

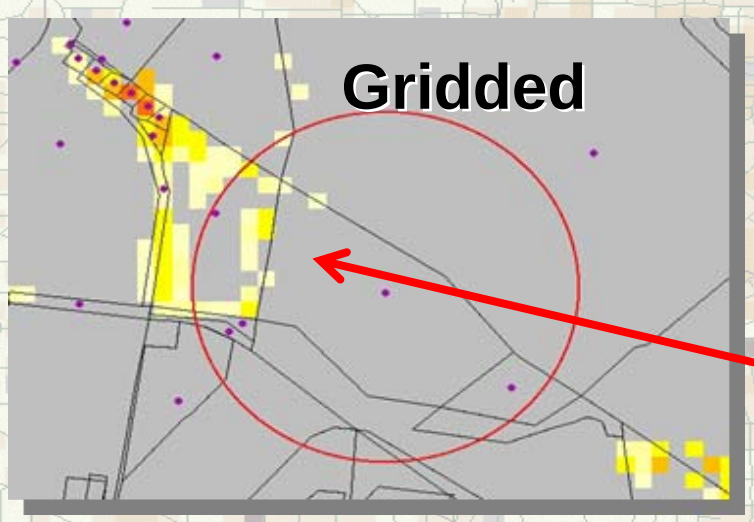
Criticality and Limitations of Population Data

- **Census data limits present modeling and simulation efforts**
  - Spatial resolution (Blocks are often too big)
  - Temporal resolution (Census is residential/nighttime)
- **Multi-simulation environments need to utilize population dynamics**
  - Function of space and time
  - Geographically scalable and deployable
  - Interoperable among simulation environments

Decomposition of Census Data



Uniform distribution assumed and all attributes associated with Census polygon centroid



More realistic non-uniform distribution of population with attributes associated with individual cells

- Point representation
- Area weighted
- Pychnophylactic interpolation
- Dasymetric modeling
- Smart interpolation

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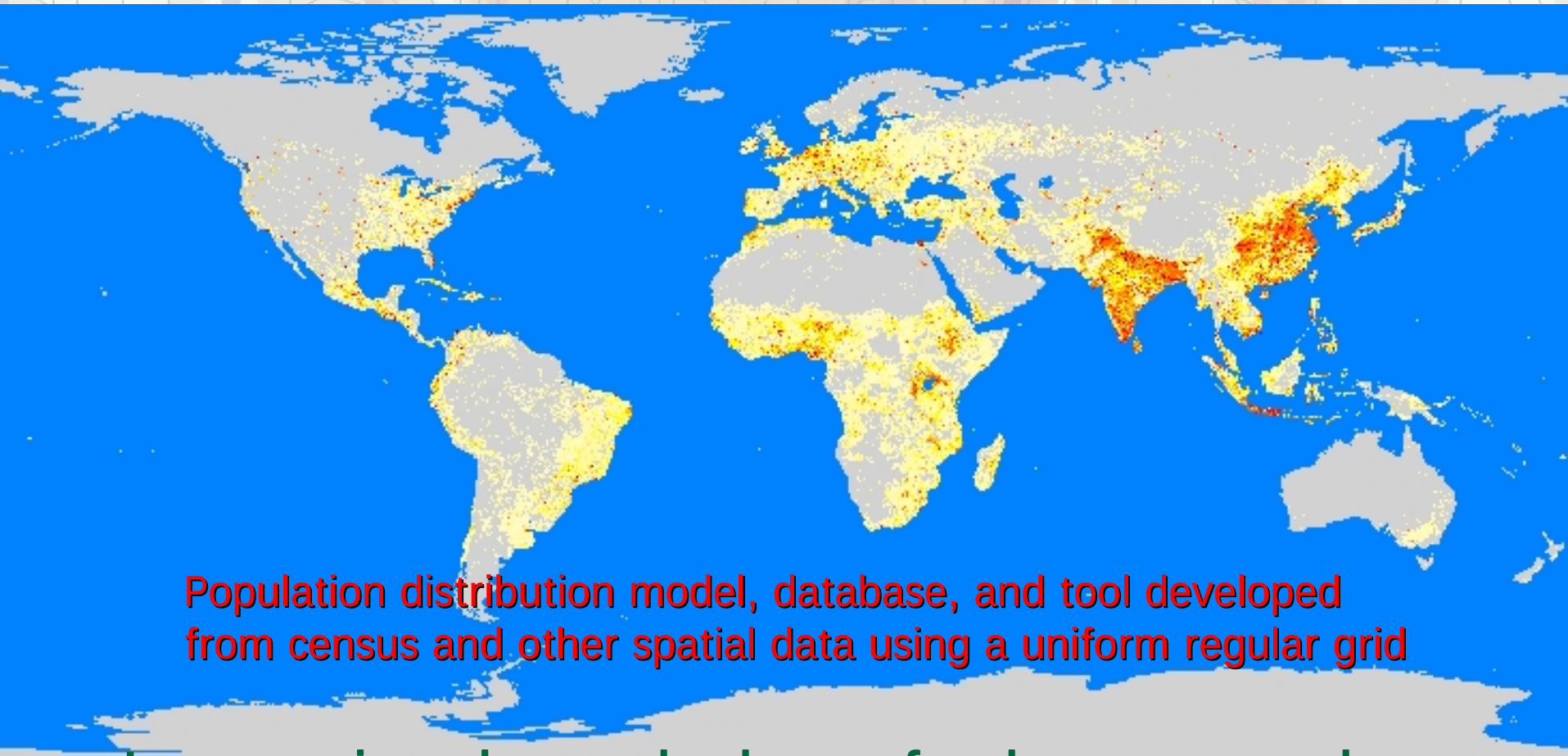
What is LandScan?



Population distribution model, database, and tool developed from census and other spatial data using a uniform regular grid

Improving knowledge of where people are located.

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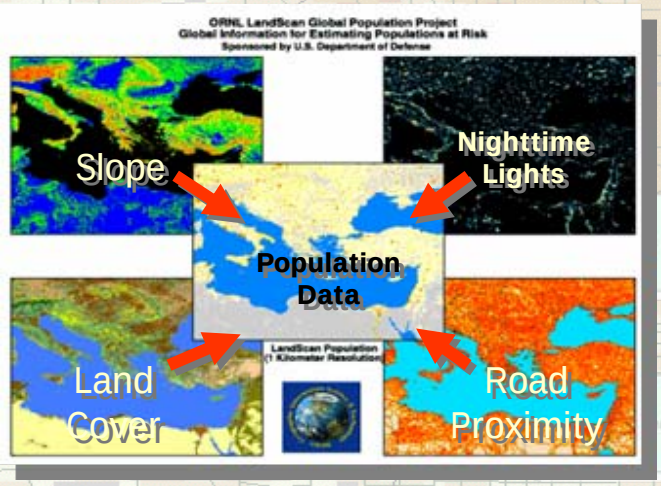
How Is LandScan Developed?



- **Dasymetric Spatial Modeling**
- **Distribute best available census counts to LandScan cells based on a likelihood coefficient calculated by this model**
- **Model structure is the same everywhere, but weights and scores for each variable are tailored to each region (Block for LandScan USA)**

H	H	H	L	L	F
H	H	H	L	F	W
H	L	L	L	F	W
H	L	F	W	W	W
L	L	F	W	W	W
L	F	F	W	W	W

H: High Density Residential
L: Low Density Residential
F: Evergreen Forest
W: Water

150	150	150	90	90	4
150	150	150	90	4	0
150	90	90	90	4	0
150	90	4	0	0	0
90	90	4	0	0	0
90	4	4	0	0	0

$$W_{Cell\,i,j} = LC_{i,j} \times PR_{i,j} \times S_{i,j} \times LM_{i,j}$$

Aggregated to Coefficient Cell Size

1230	372
526	0

3250	630
1120	0

$$PC_{Block} = \frac{Total\ Population_{Block}}{\sum_{1}^{n} W_{Cell\,i,j}}$$

325	63
112	0

$$Population_{Cell\,i,j} = PC_{Block} \times W_{Cell\,i,j}$$

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LandScan Global Population

Innovative approach using GIS and RS techniques to produce world's finest population distribution model, database, and tool

- Finest spatial resolution (<1km) global population distribution ever produced
- Global coverage in consistent raster (GIS) format
- Regular (yearly) updates
- First to employ satellite imagery worldwide
- Allows quick and easy assessment, estimation, and visualization of population at risk
- Integrated with transportation, socioeconomic, and consequence assessment models (HPAC)

- Community standard for estimating population at risk by the international community
- Federal agencies including DoD (DTRA, NGA), DHS (FEMA, TSA), DOE, USGS, NASA, EPA, and HHS (CDC, NIH) are current users of the data for research and development and routine exercises
- Over 1200 non-defense registered users worldwide including WHO and the UN agencies
- Used in Rand McNally's World Goode's Atlas and National Geographic Maps

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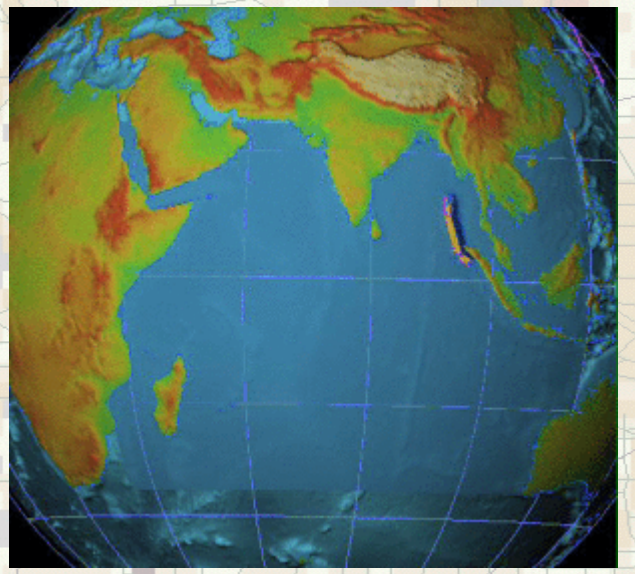
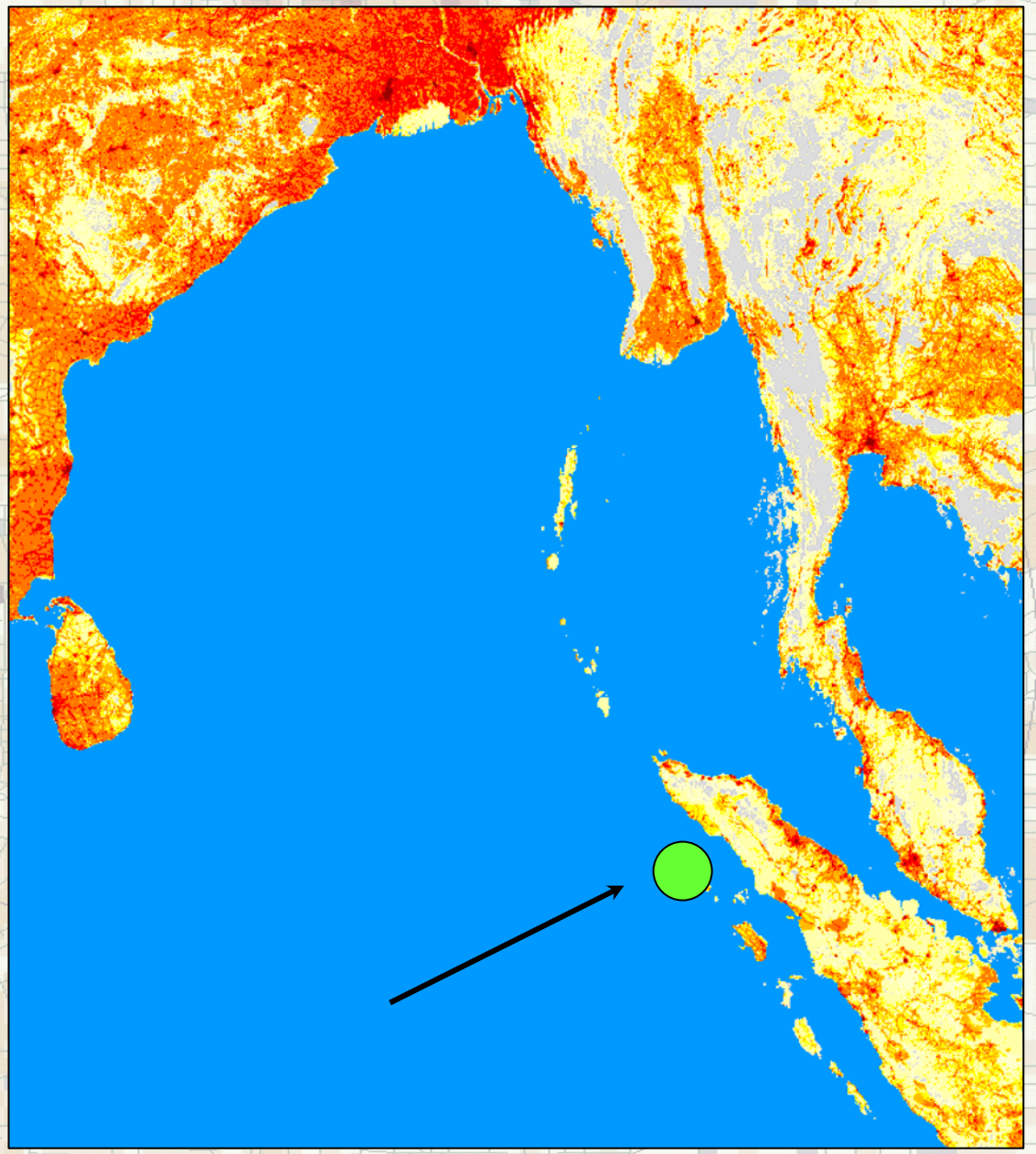


Earthquake Location and Tsunami Region

With

LandScan Population



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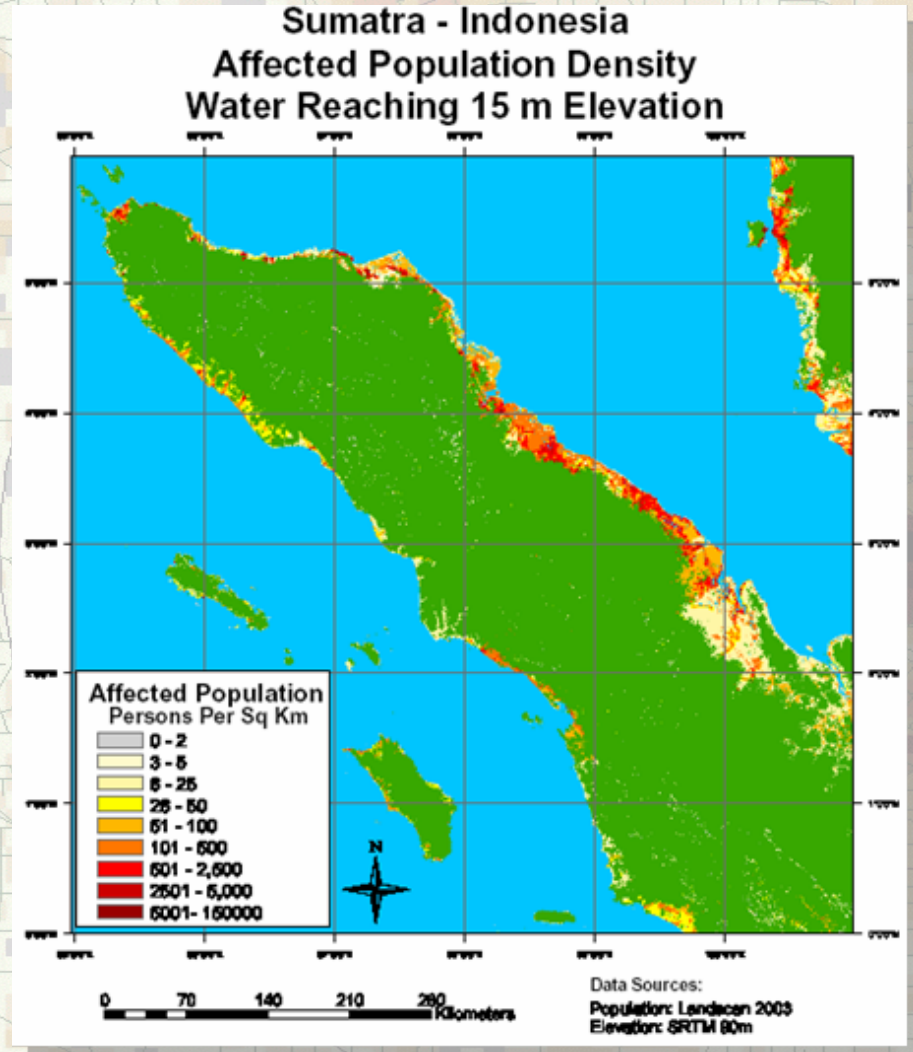
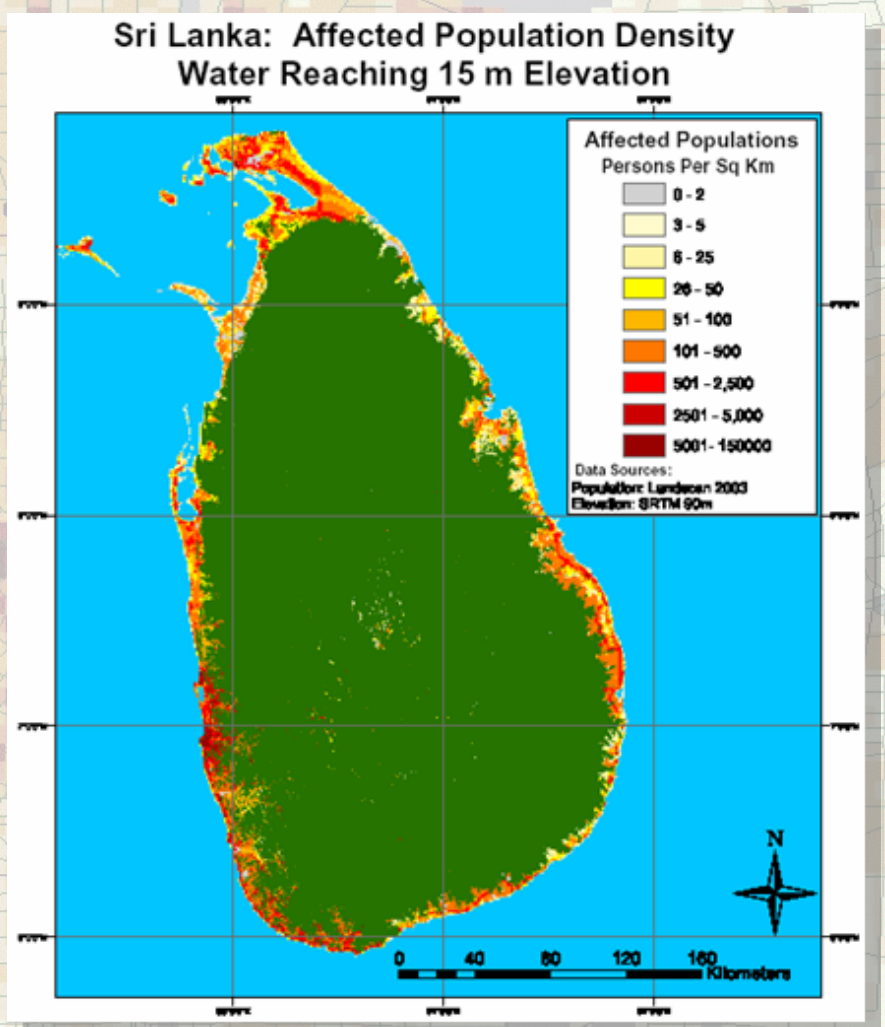
Preliminary Maps made by USGS using LandScan





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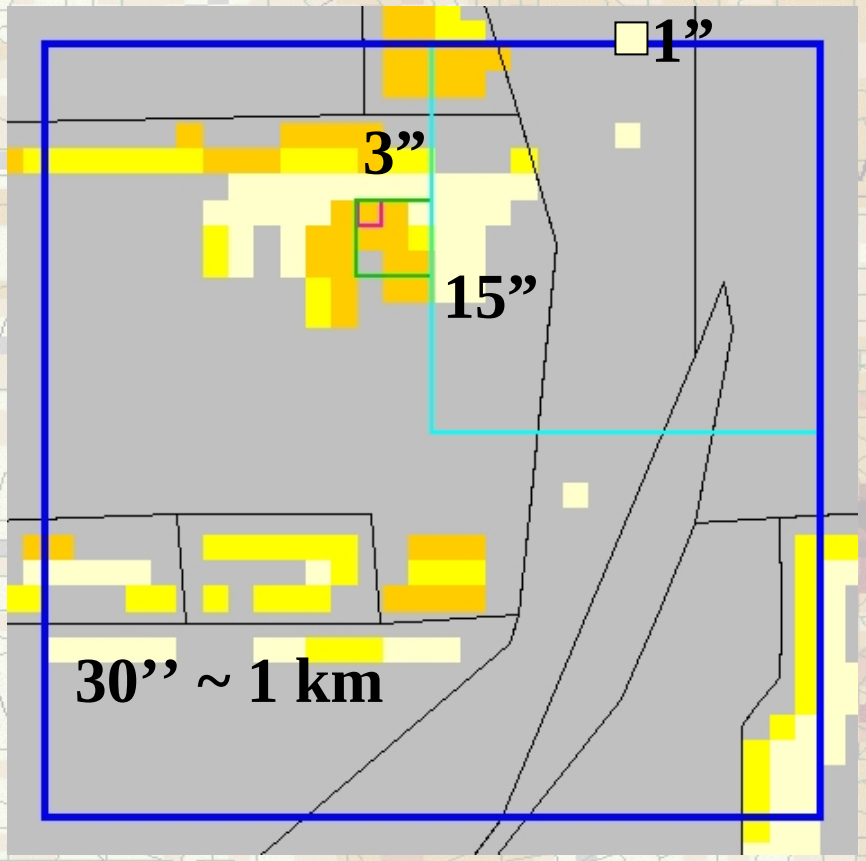
LandScan Spatial Resolutions



LandScan Global, LandScan USA Interim, and LandScan USA data resolutions are shown by the blue, light blue, and green squares

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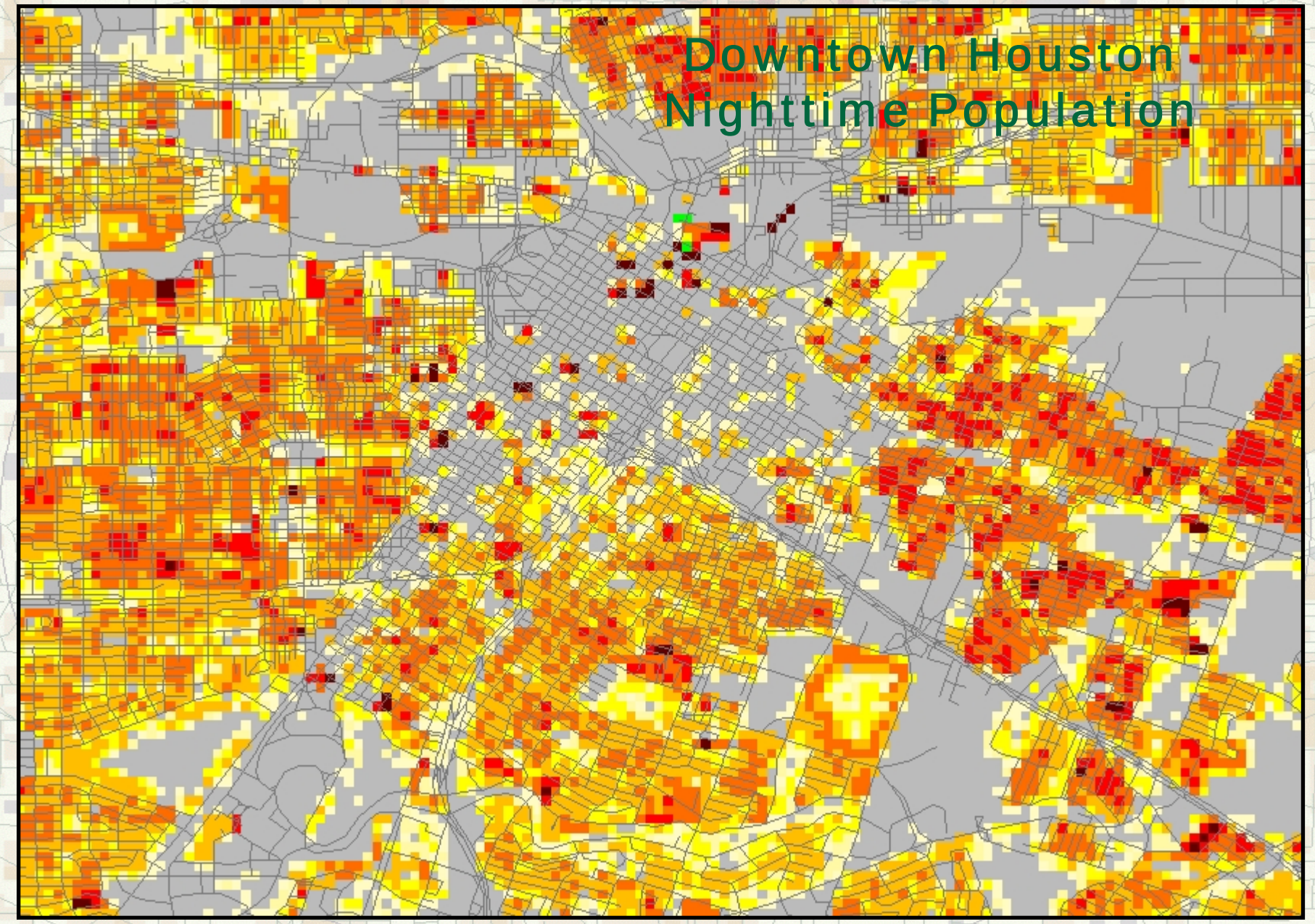
Input Data Smorgasbord

- **Population**
  - Census Block; Tract-to-track worker flow; BLS quarterly updates.
- **Roads**
  - GDT Dynamap; TIGER;
- **Land Cover/Land Use**
  - National Land Cover Data (NLCD); State GIS;
- **Slope**
  - National Elevation Data (NED)
- **Academic Institutions**
  - Department of Education; ESRI; GDT;
- **Prisons**
  - National Jail Census
- **Hospitals & Hotels**
  - American Hospital Association (AHA)
  - STR Hotels
- **Business Employment**
  - InfoUSA;
- **Ortho Imagery**
  - EarthViewer; Terra Server.



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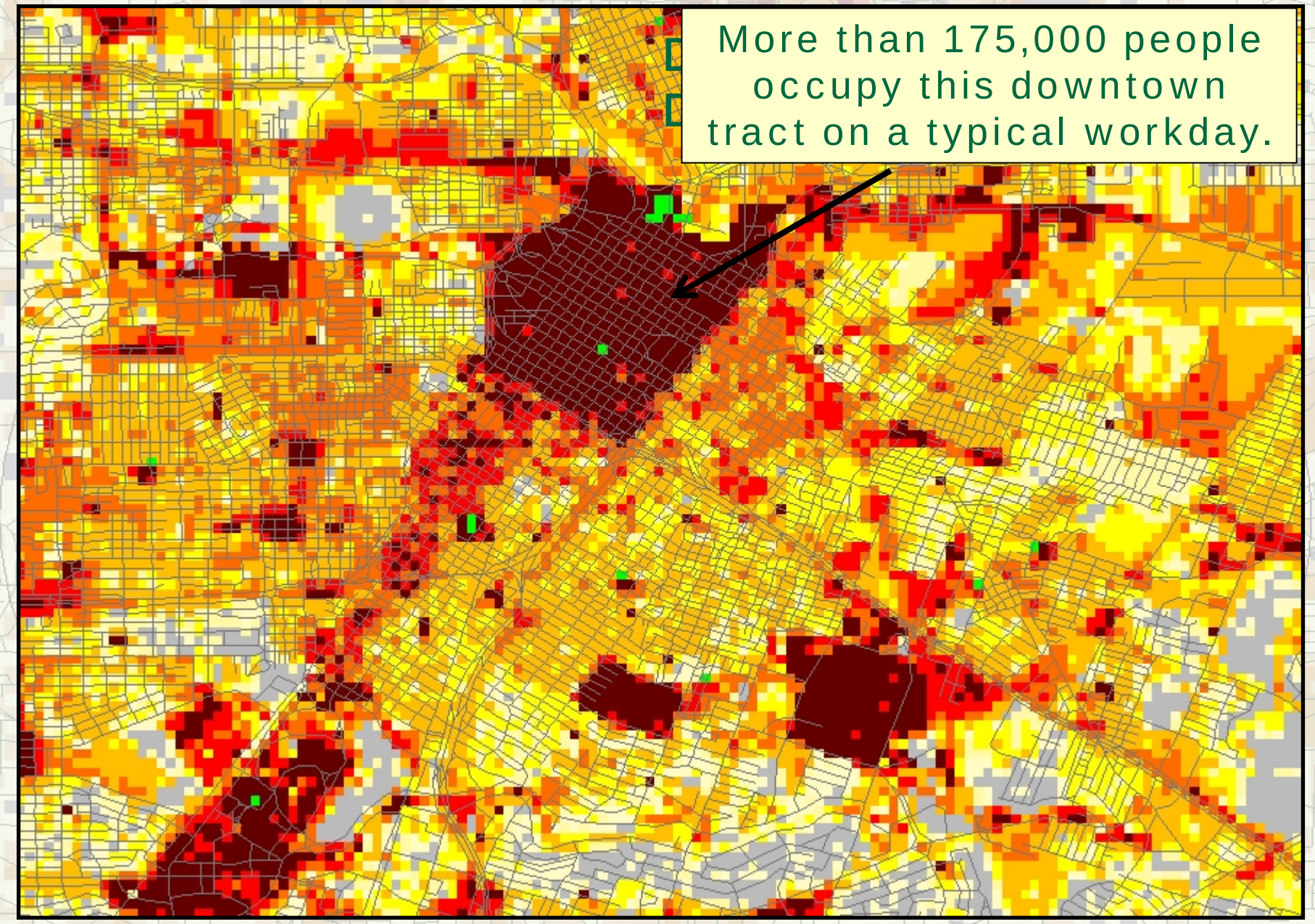

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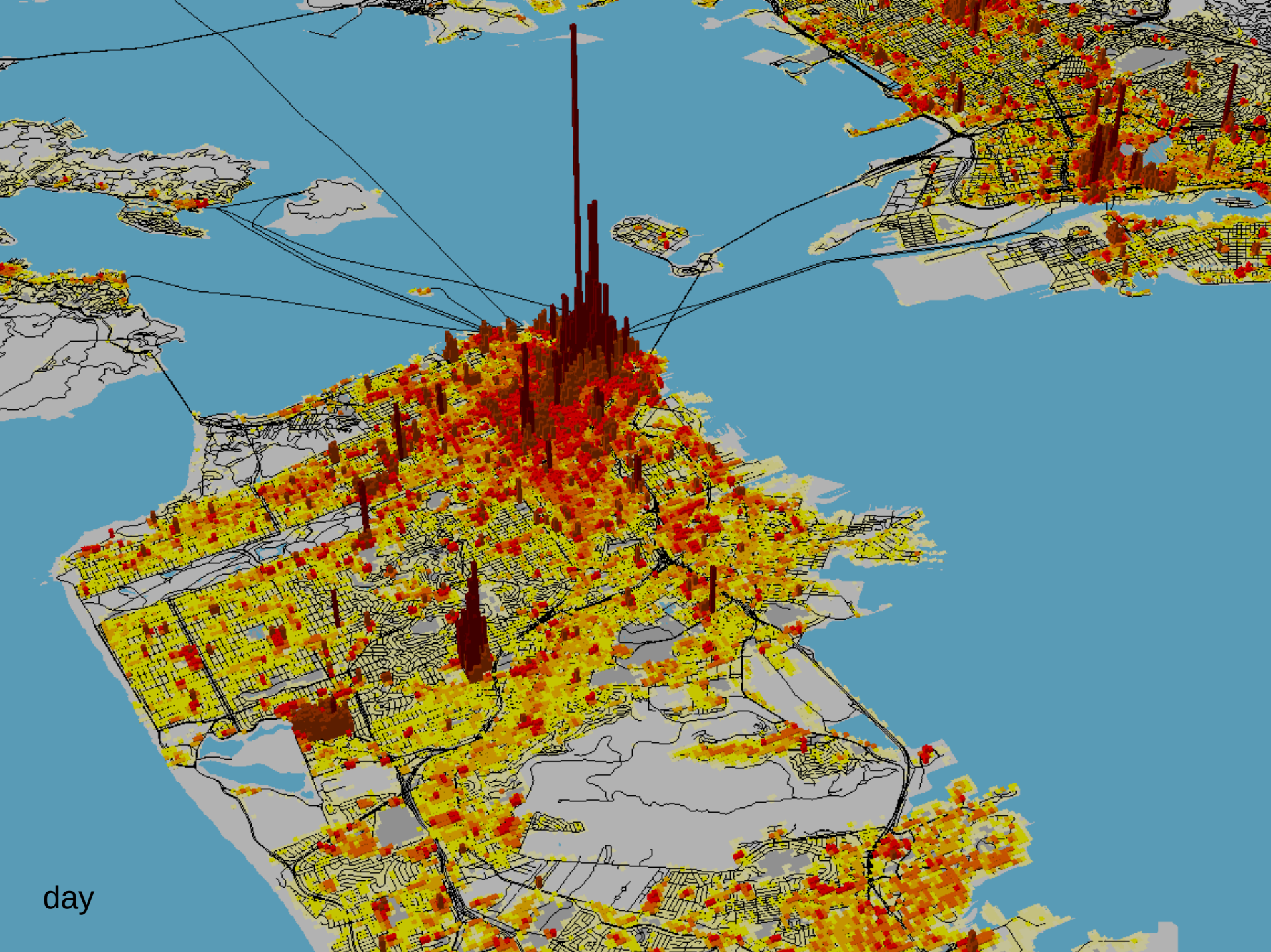
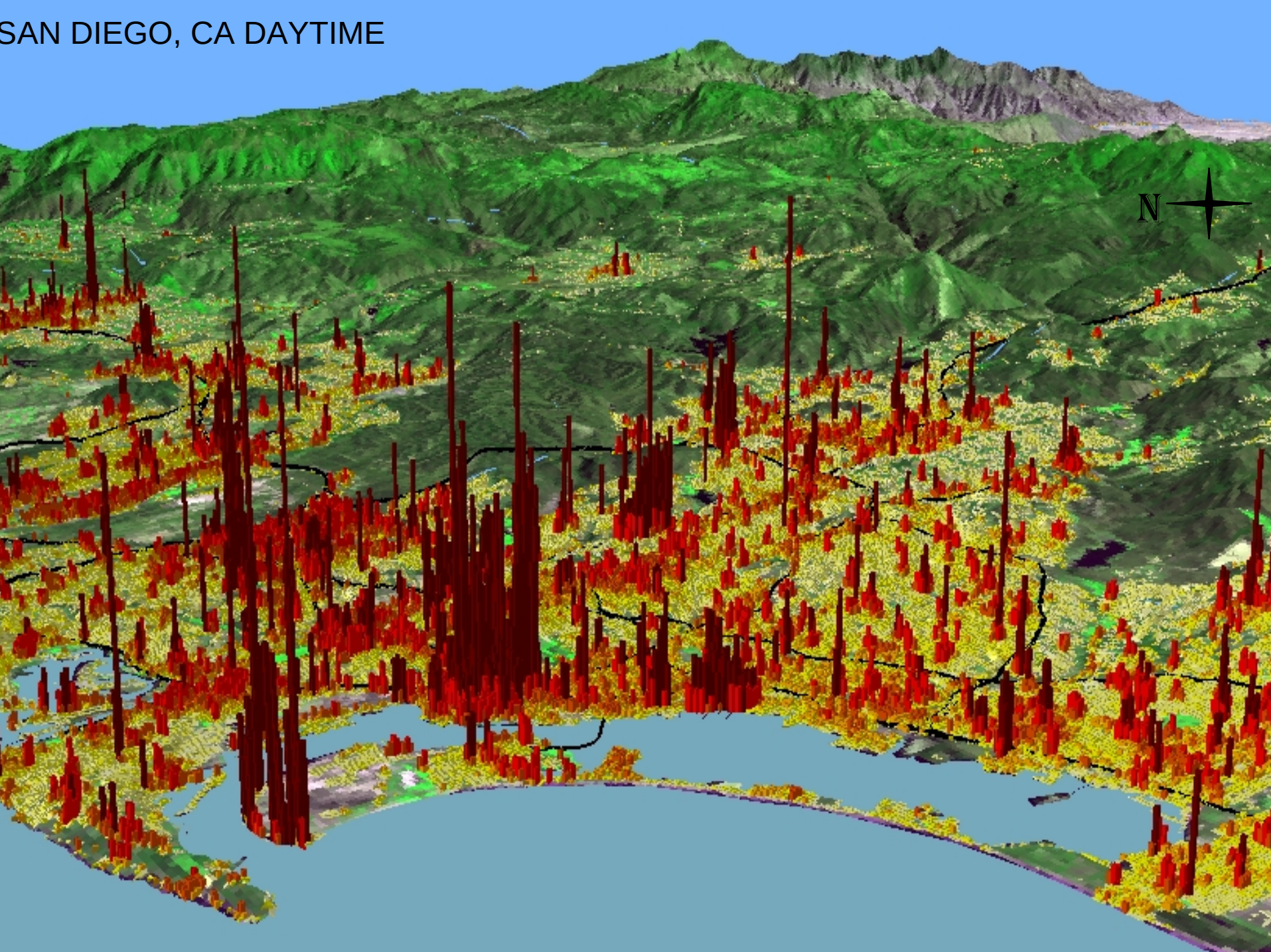
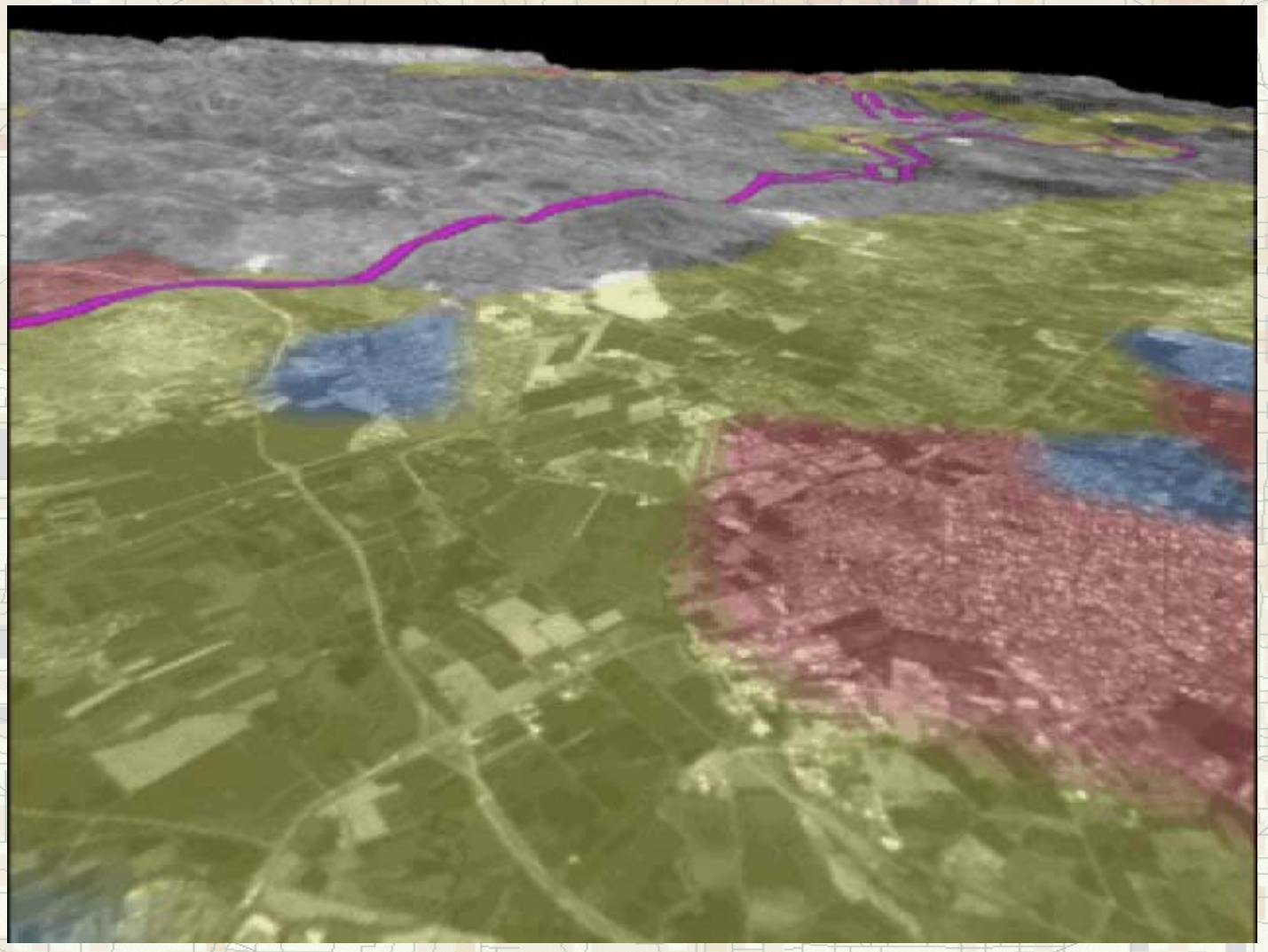

day

SAN DIEGO, CA DAYTIME

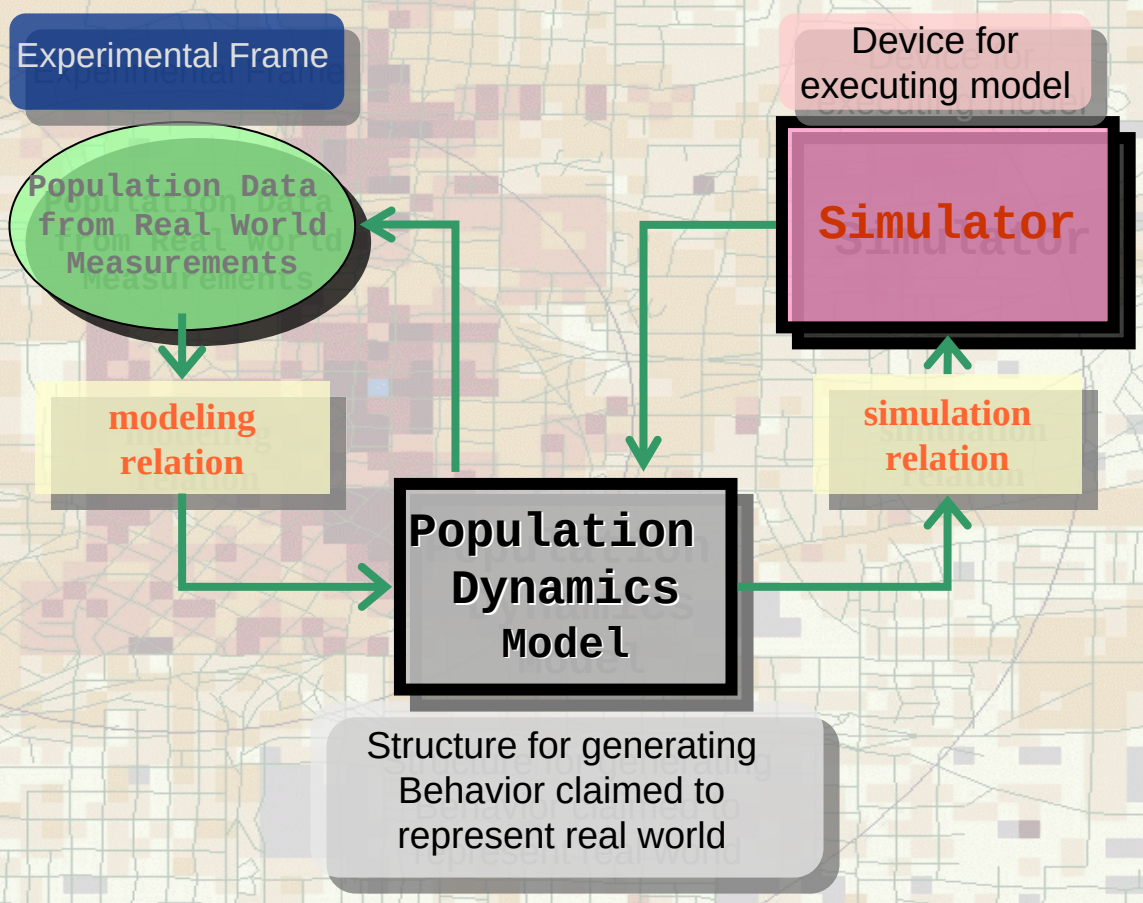


Space-Time Dynamic



Modeling & Simulation Framework

- **Real System:** A source of data (behavior).
  - Ant colony, social networks, falling objects, etc.
- ***Model***: A set of instructions and/or equations for generating data comparable to that in the real system.
  - Logical statements, differential equations, and other mathematical and/or semi-formal tools
- ***Simulator***: Exercises the model's instruction to actually generate behavior.
  - Computer and simulation algorithm



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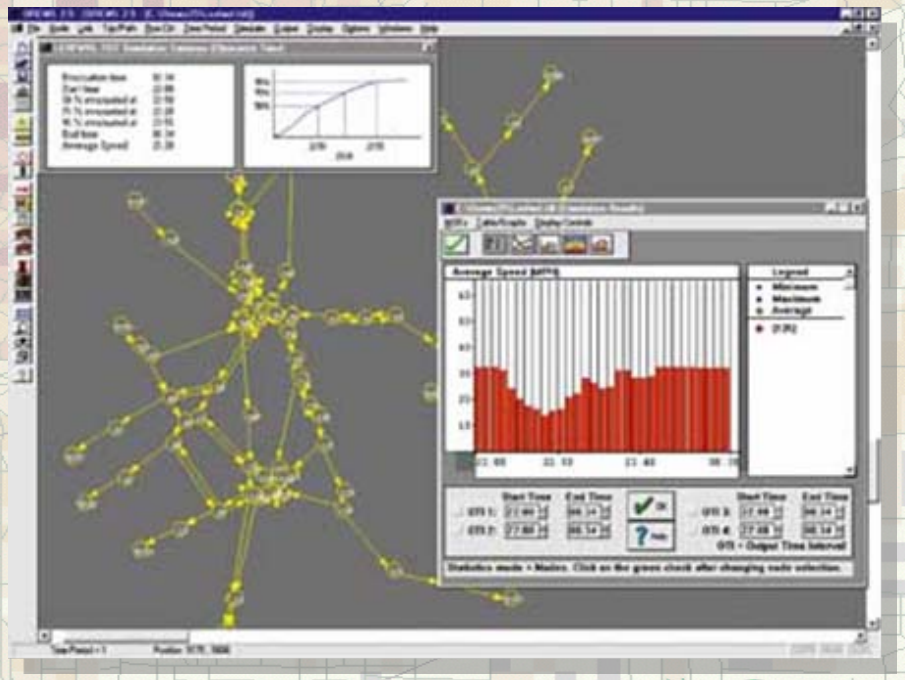
Intelligent Evacuation Modeling

- **Standardized approaches for integrating behavioral, economic, and physical models using GIS**
- **Develop prototype of a model**
  - Conduct local analyses on a national basis
  - Has sound behavioral assumptions
  - Uses detailed demographic data
  - Simulation learns over time
  - Capable of using real-time data
  - Models faster than real-time
  - Use as a planning and response tool

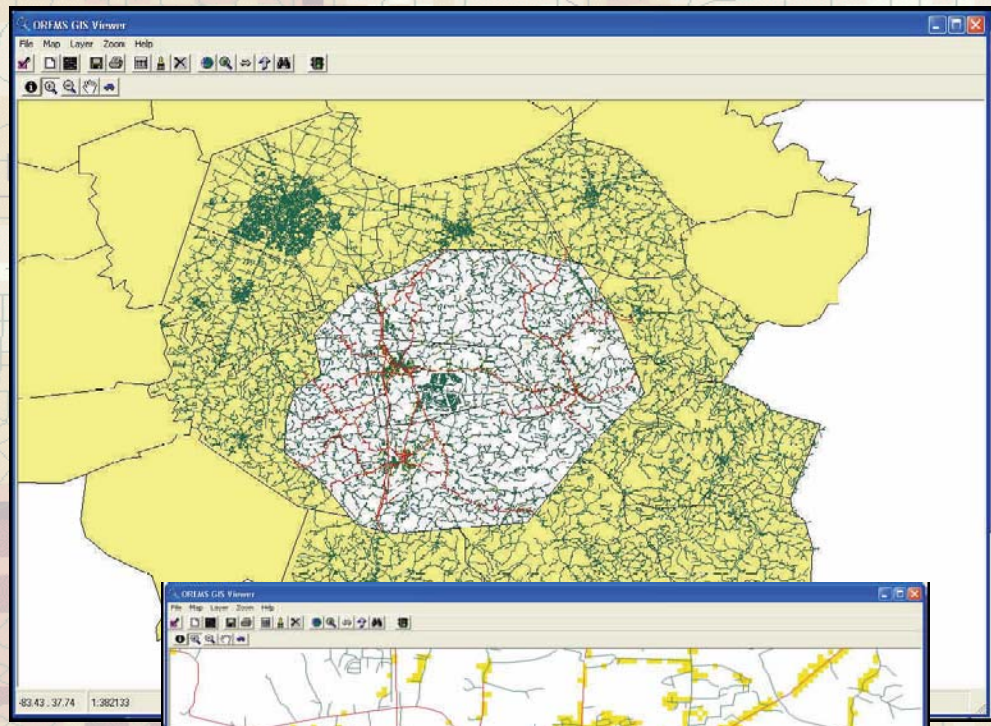
OREMS Background

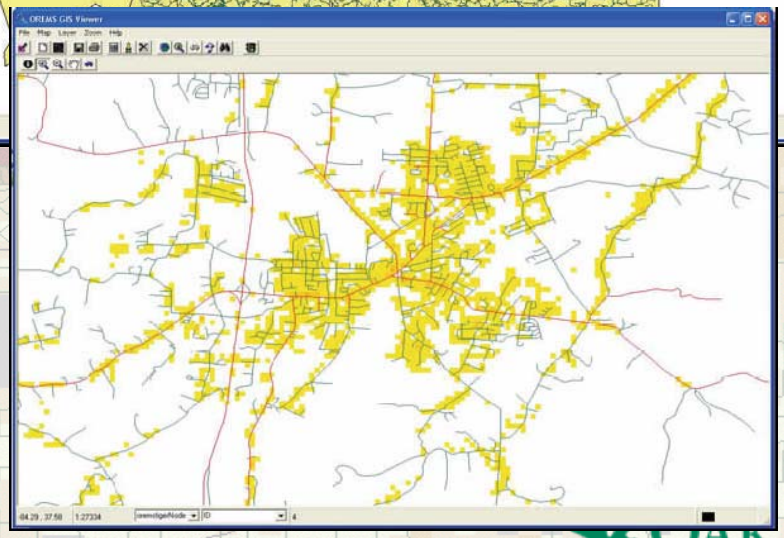
- **Network-based simulation model for urban evacuation developed in the early 1990s for FEMA and U.S. Army**
- **Based on DOT traffic simulation codes**
- **Evacuation planning uses**
  - Evacuation time estimates
  - Route optimization
  - Traffic management strategies
  - Identification of bottlenecks
  - Scenario analysis



OREMS Enhancements

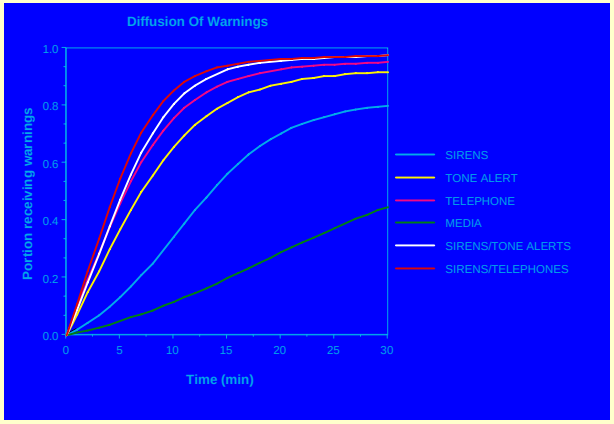
- **Developed a geospatial framework**
- **Developed a network generation model**
- **Improved assumptions of human behavior**
- **Replaced static traffic assignment with dynamic assignment code**
- **Integrated with high resolution ORNL population/demographic database**

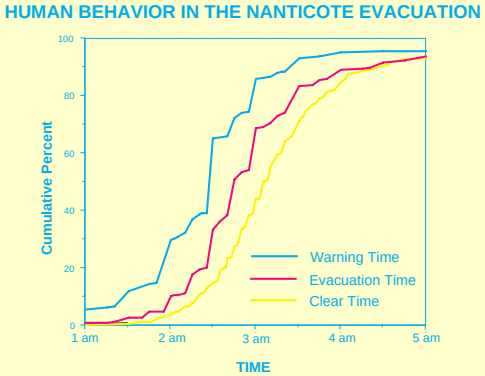




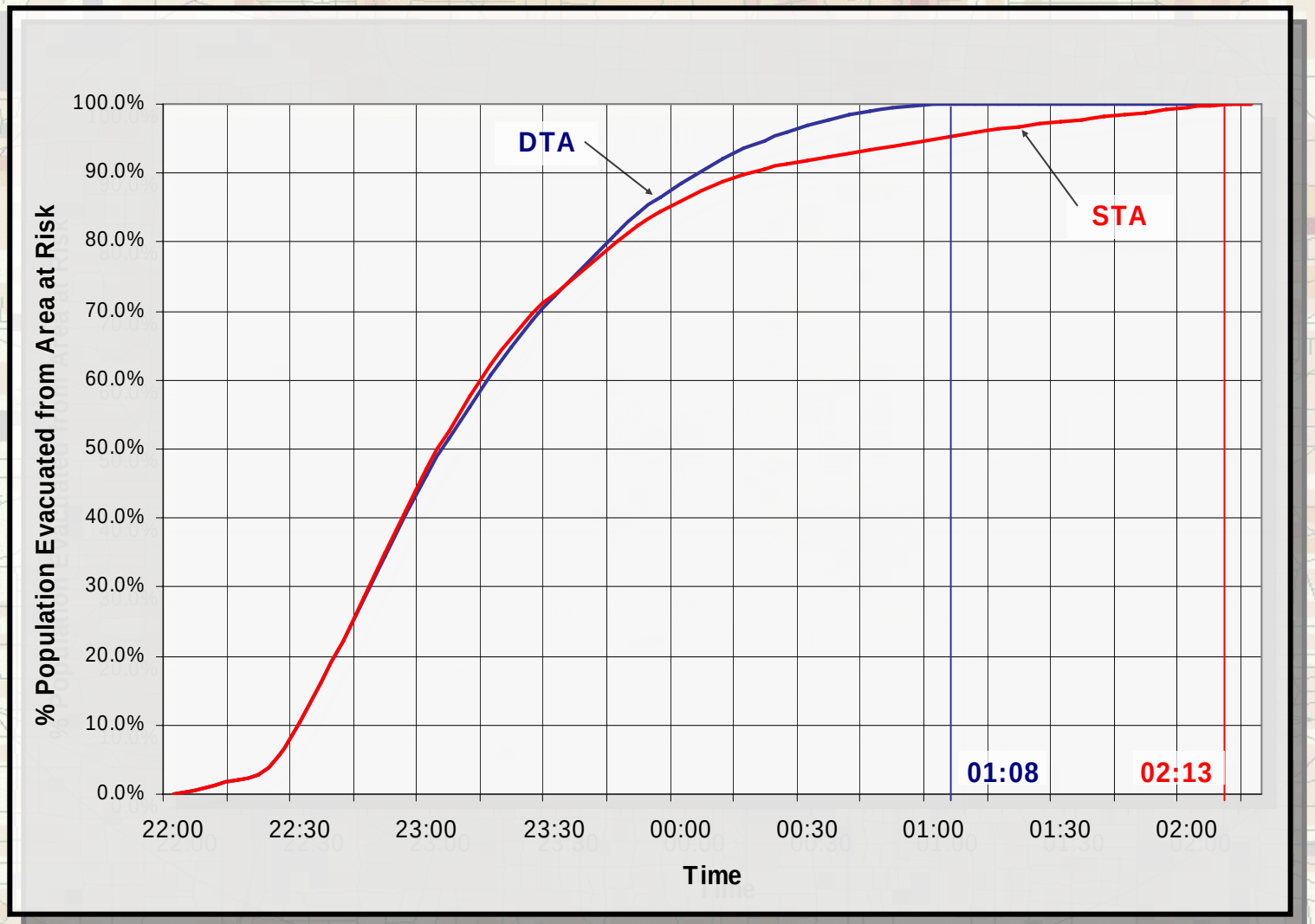
Assumptions on Behavior

- **Utilized data from research on warning response**
- **Developed models of warning diffusion**
- **Developed models of preparation and mobilization time**
- **Used to estimate traffic loading functions**



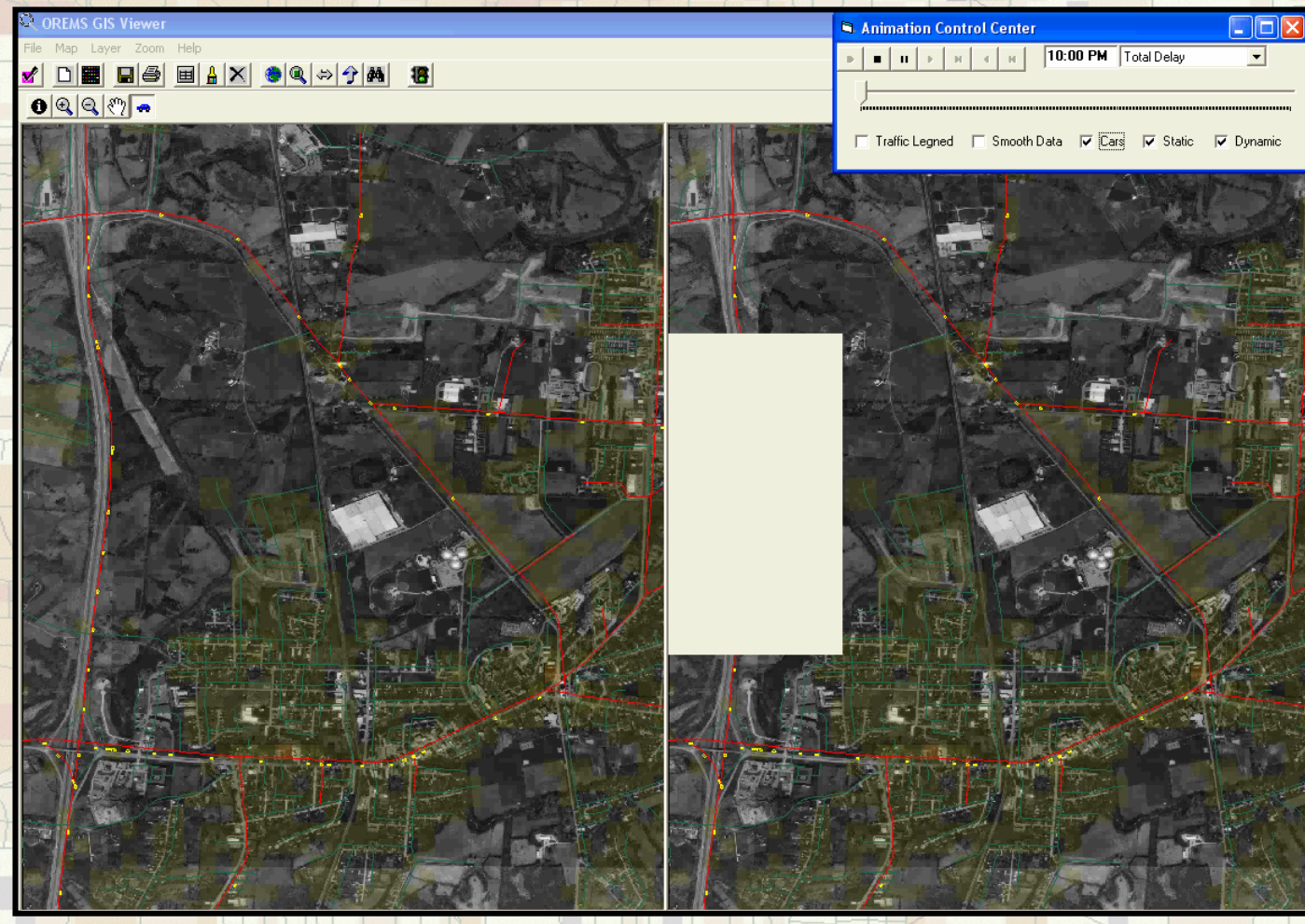


Static vs. Dynamic TA Model Results



Intelligent Consequence Management

- Real time consequence analysis
- Compounding effects from disasters
- Dynamic traffic assignment
- GIS-data integration
- Sensitivity of lead time



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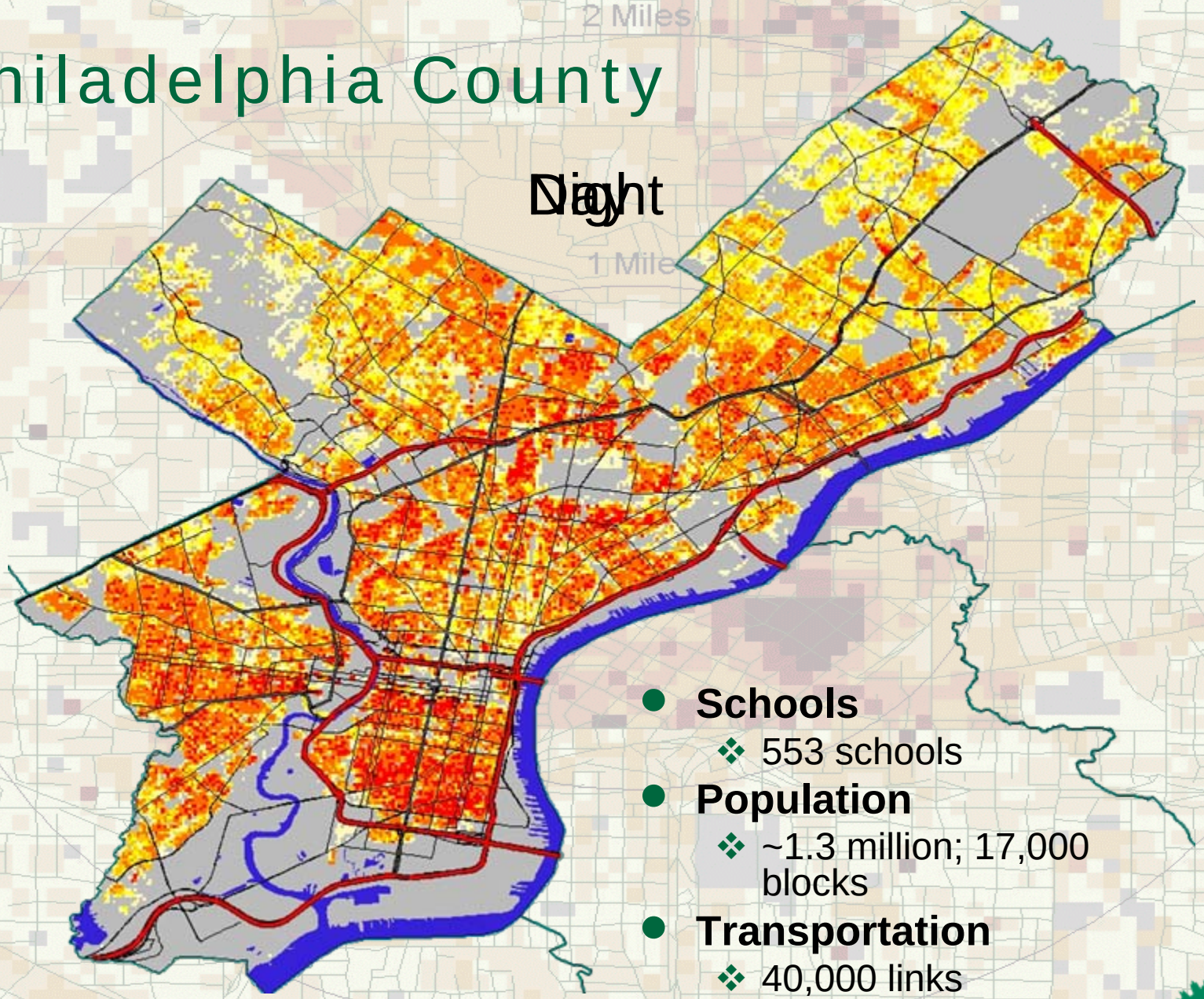
Philadelphia County



- **Schools**
  - 553 schools
- **Population**
  - ~1.3 million; 17,000 blocks
- **Transportation**
  - 40,000 links

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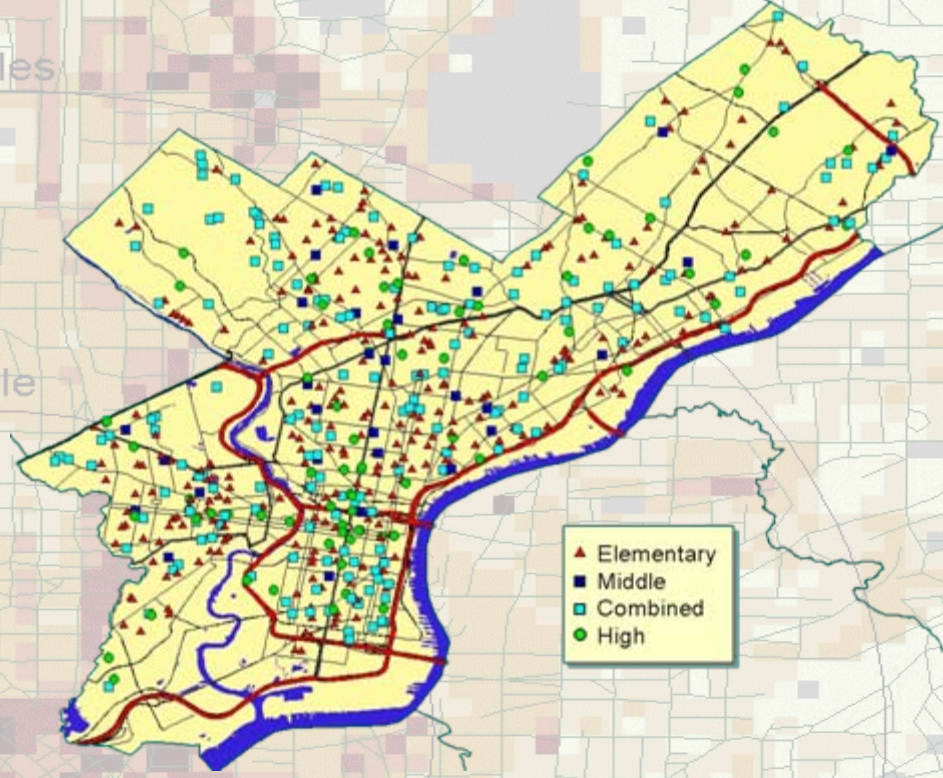
Schools Data

	Age	LandScan
KG	5	21,081
Elementary	6-11	106,319
Middle	12-14	63,729
High	15-18	96,676
Total		287,805



School Type	Number
KG	6
Elementary	269
Middle	30
High	72
Combined	168
Special/New	8

	LandScan	NCES	Enrollment
Public (02-03)	315	307	213,696
Private (01- 02)	238	242	68,482
Total	553	549	282,178

NCES: 1.5% home schooled

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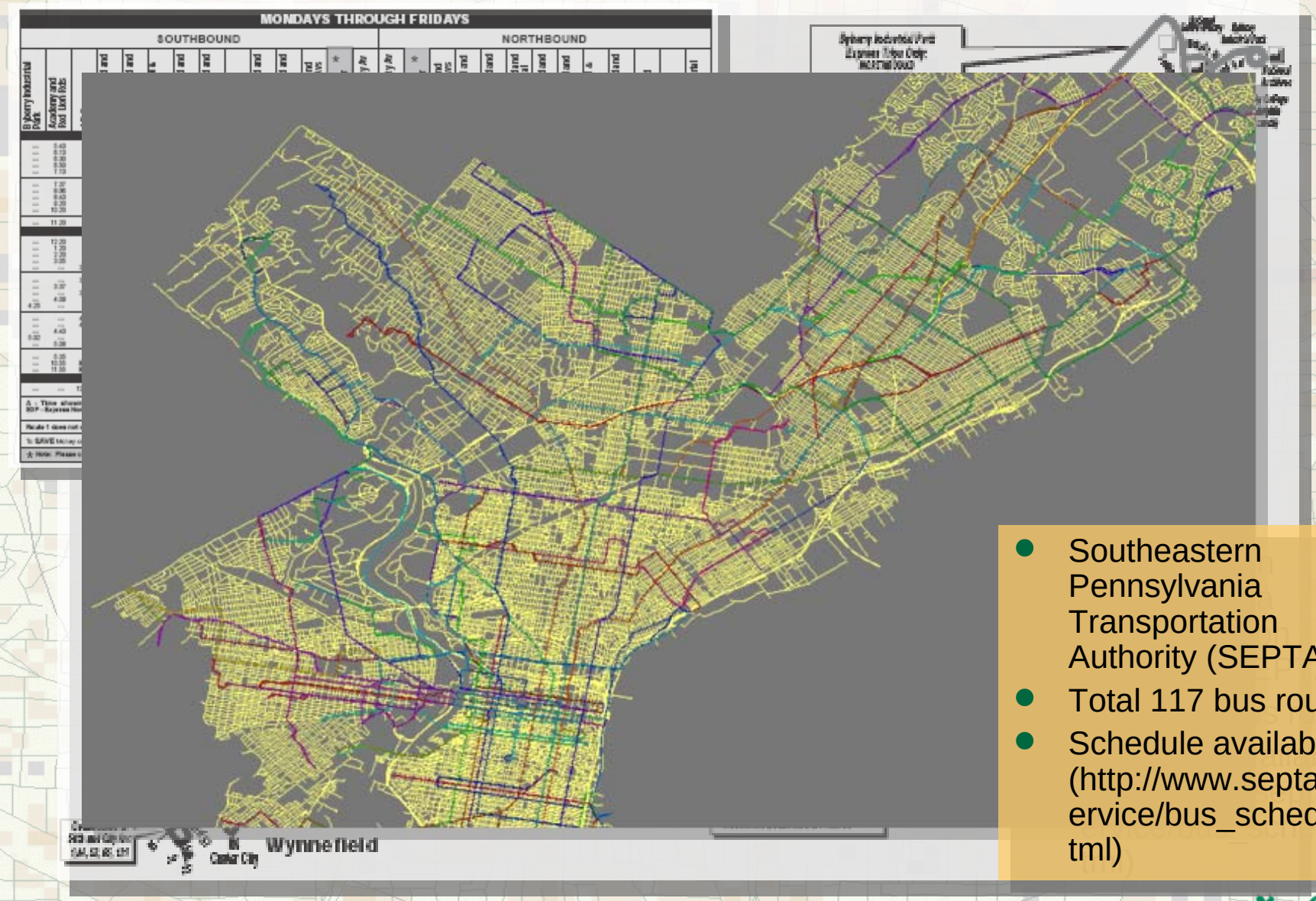
Public Bus Routes



- Southeastern Pennsylvania Transportation Authority (SEPTA)
- Total 117 bus routes
- Schedule available (http://www.septa.org/service/bus_schedules.html)

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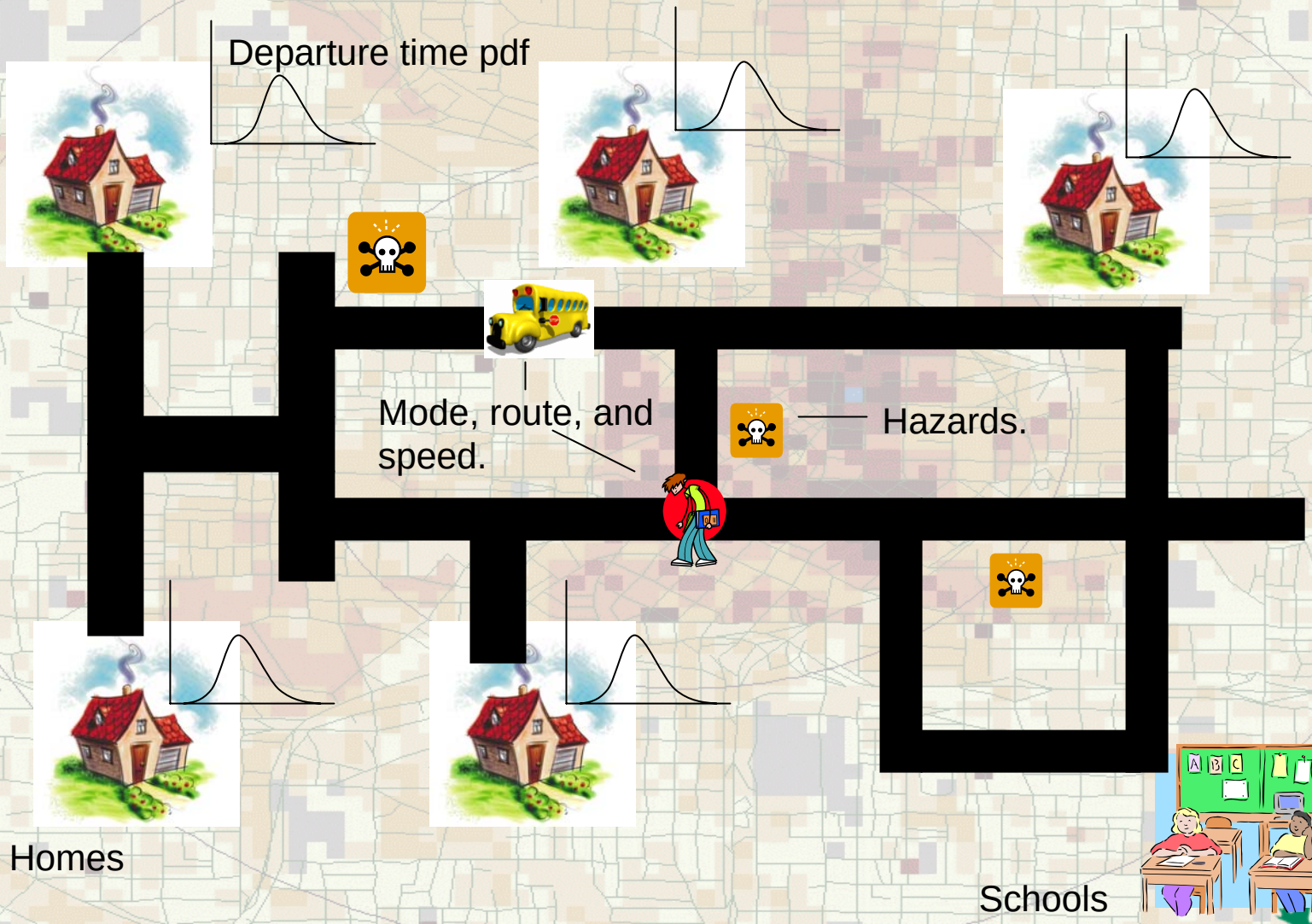
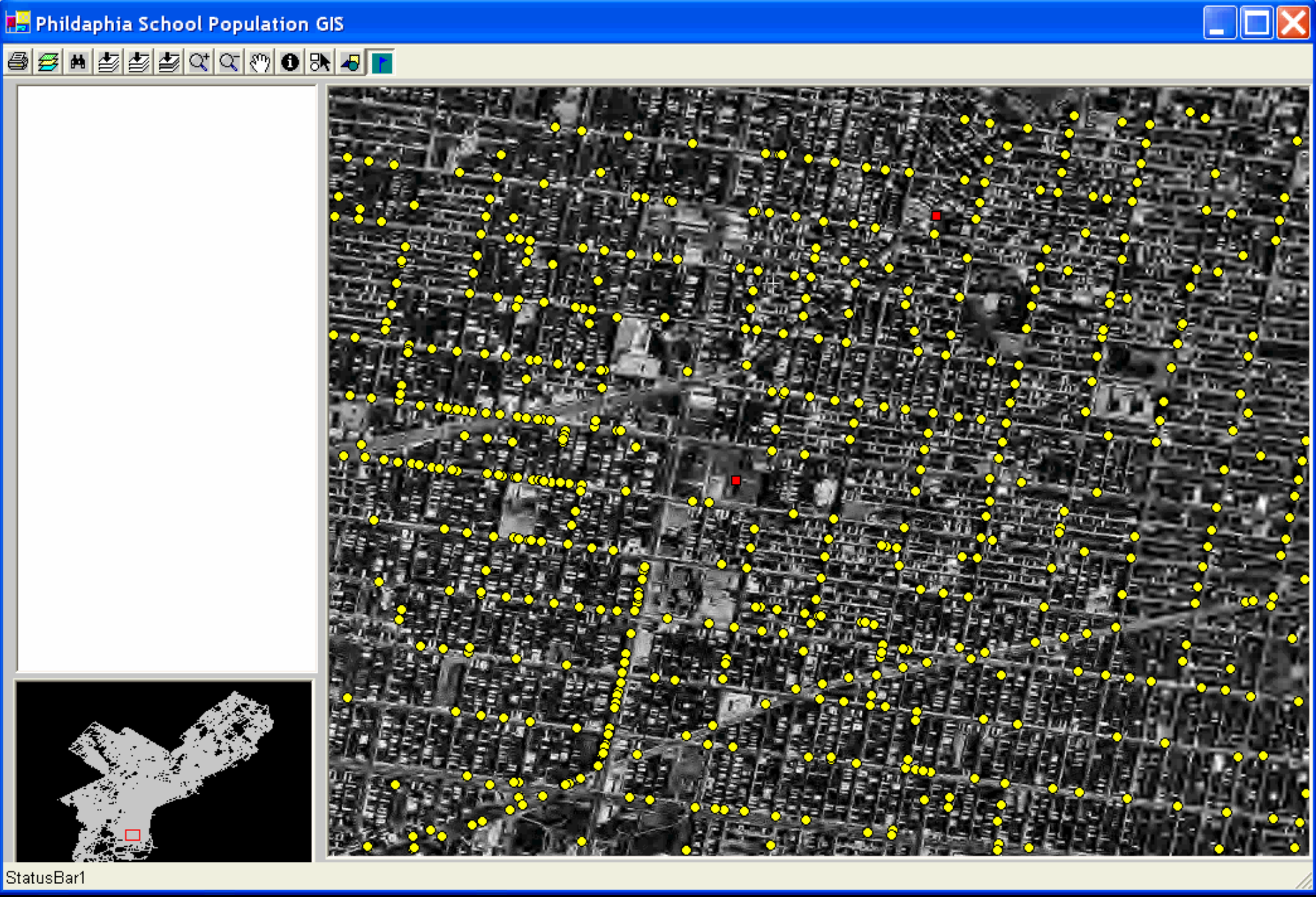
Daily School Commute Events



Commute Simulation Algorithms

- **Routes and**
  - Students who drive or walk follow the shortest path from home to school and back.
  - Students on the bus follow a fixed route.
- **Speeds**
  - Single mode
    - Walk (4 miles/hour)
    - Bike (15 miles/hour)
    - Bus, Car, Taxi (25 miles/hour on the service streets and 55 miles/hour on the highway)
  - Multi-mode
    - Bus
      - Walk – Bus - Walk
- **Departure times and modes**
  - Example: 7-8 am arrival and 3-6 pm departure
  - Exploring suitability of CHAD data for use in the model

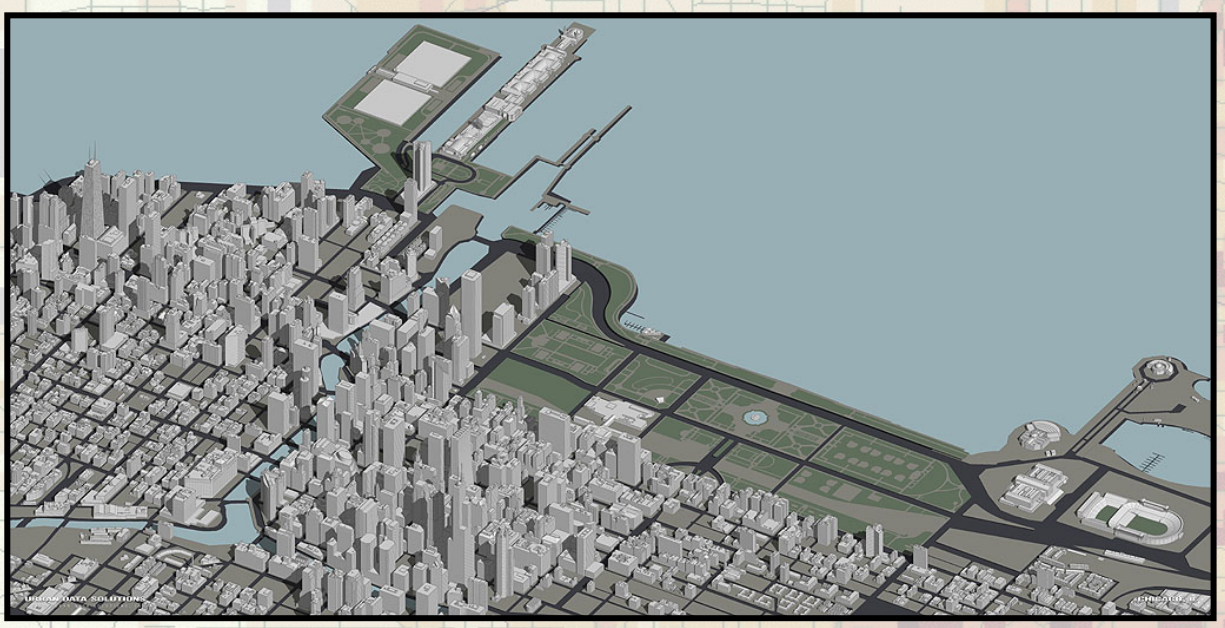


Walk: 3 mi/hr, < 1mi; Bike: 6 mi/hr, <4 mi; Car: 45 mi/hr, >4 mi

Research Priorities

- **Understanding of errors and uncertainties in data and model**
- **Population dynamics**
  - Space-time mobility and sensitivity to geographic scale
  - Backcasting and forecasting methods and models
- **Demographic analysis**
  - Demographic variations in space and time
  - Urban-rural distributions; poverty mapping

Near-Real Time Population Dynamics Model



Combining

- **Sensor Data**
- **Image processing**
- **GIS modeling**
- **High-performance computing**

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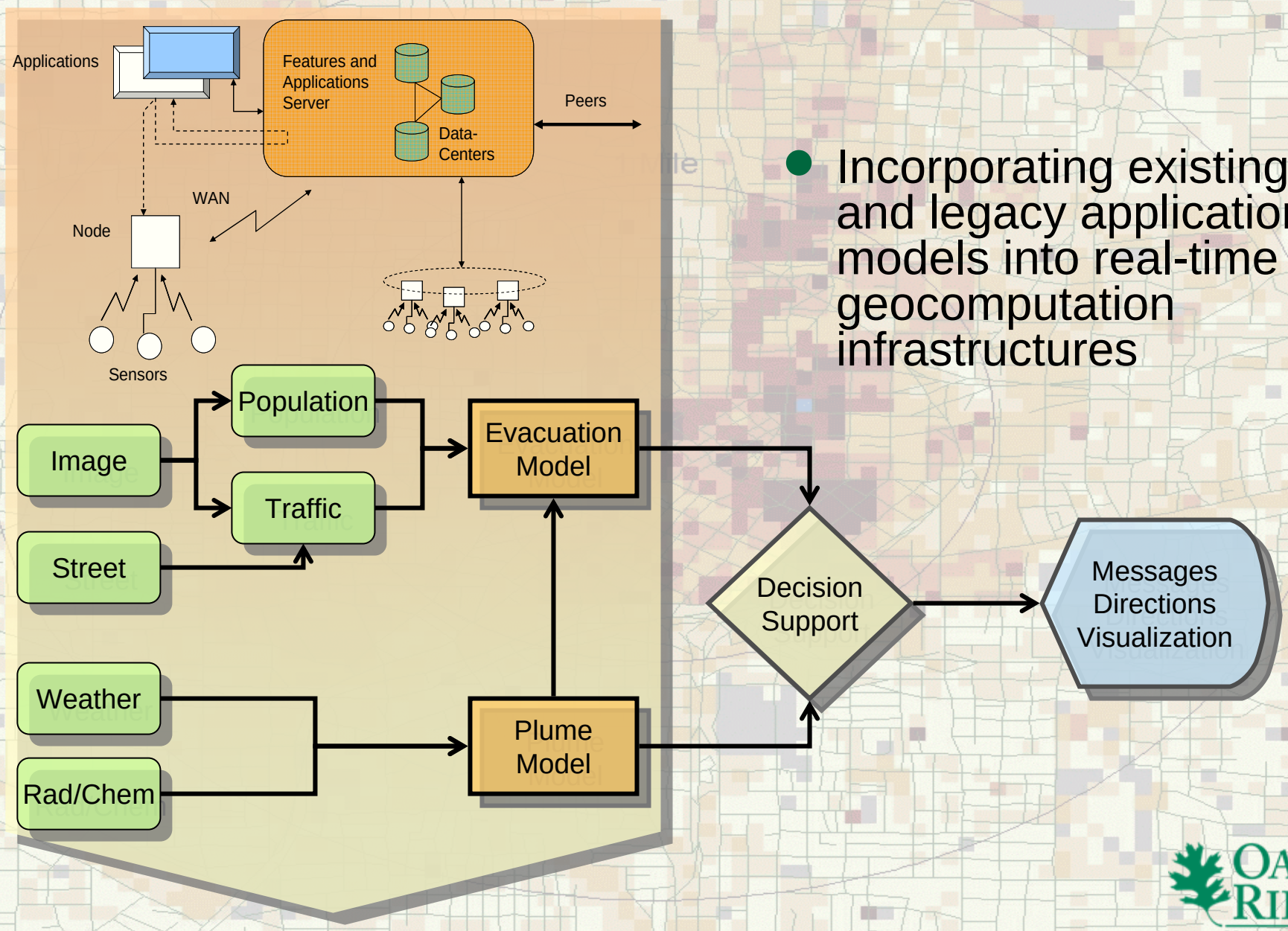
SensorNet: Dynamic Geocomputation



- Incorporating existing and legacy application models into real-time geocomputation infrastructures

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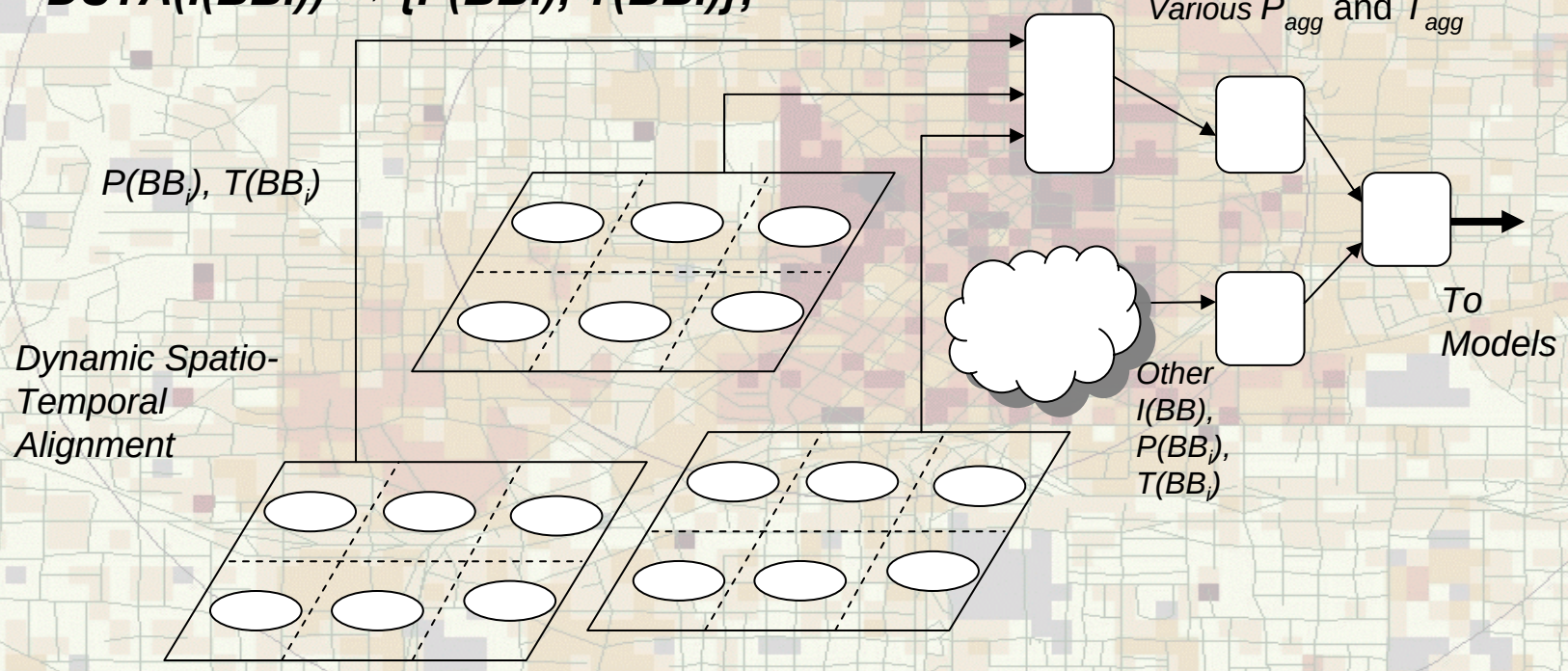
Dynamic Spatio-Temporal Alignment Module (DSTA)

- **The Dynamic Spatio-Temporal Alignment module takes image and traffic sensor data and converts it to a form usable by the evacuation model.**

DSTA(I(BBi)) → {P(BBi), T(BBi)},



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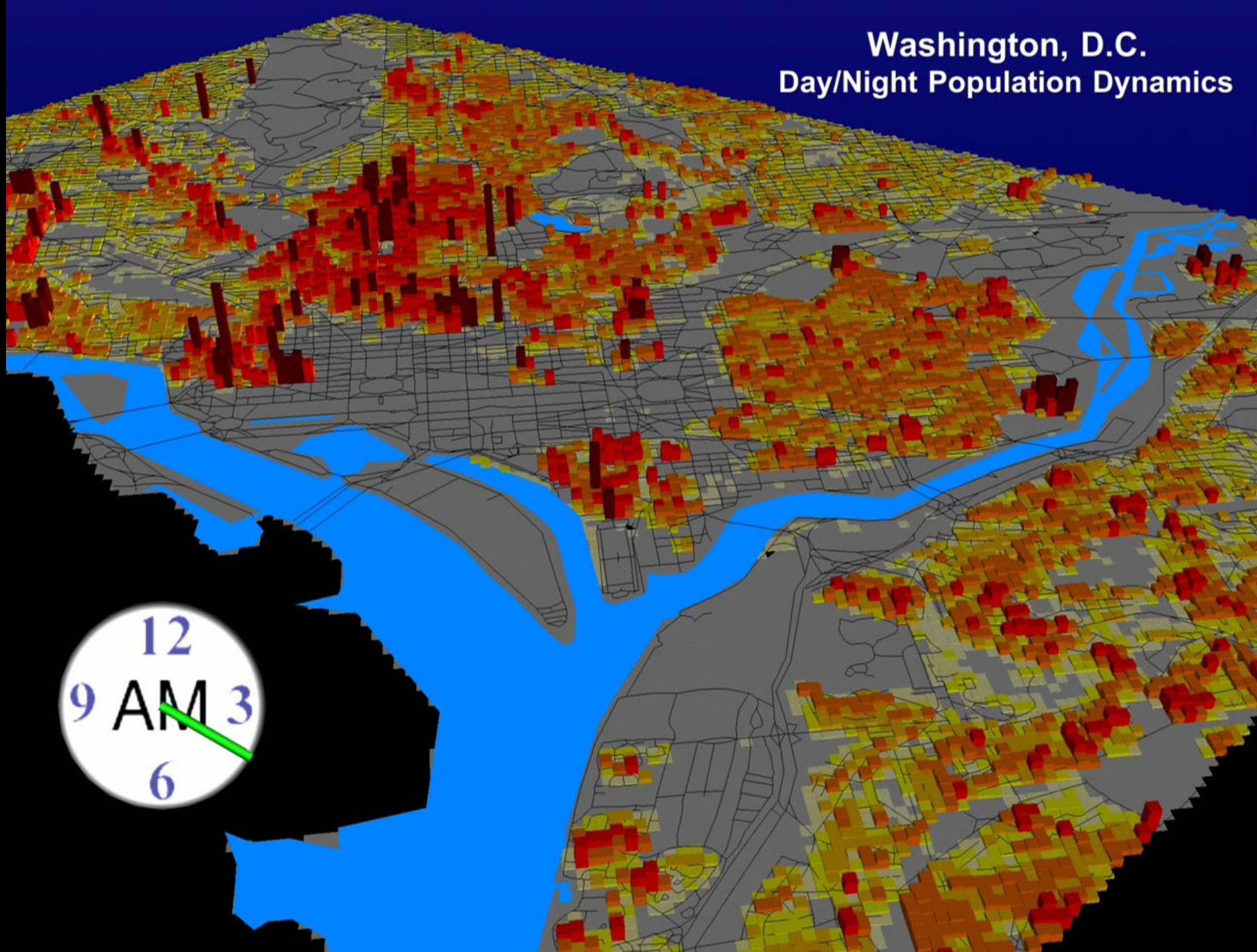
Washington, D.C.
Day/Night Population Dynamics
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6