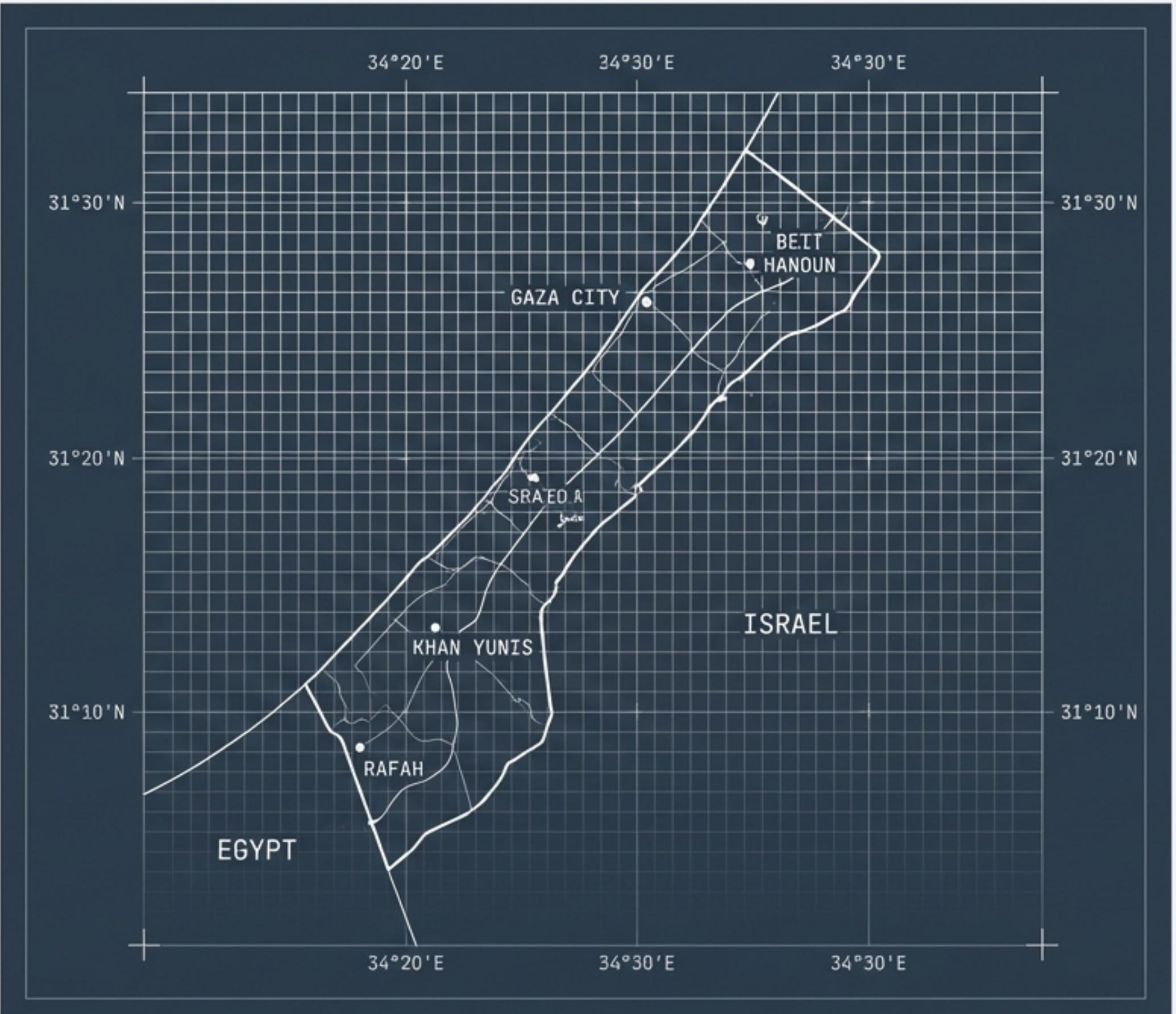


Mapping the Unseen

Data Fusion for Population Estimation in Gaza

A technical workflow combining Satellite Imagery, Infrastructure Data, and Mobility Metrics.

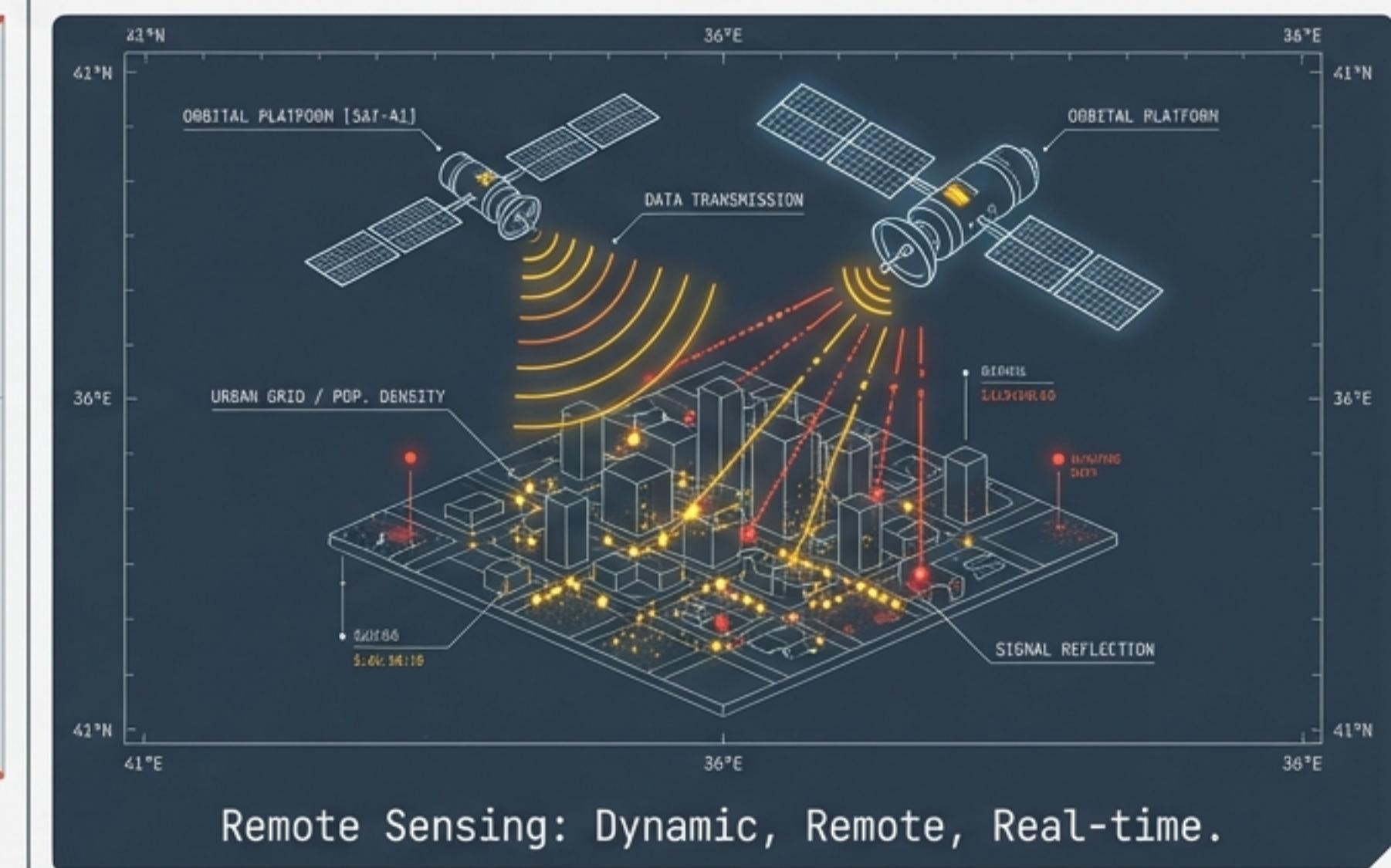


Methodology: Layered Intelligence Framework

The Challenge of Estimating Population in Crisis



Traditional Census: Static, Outdated, Inaccessible.

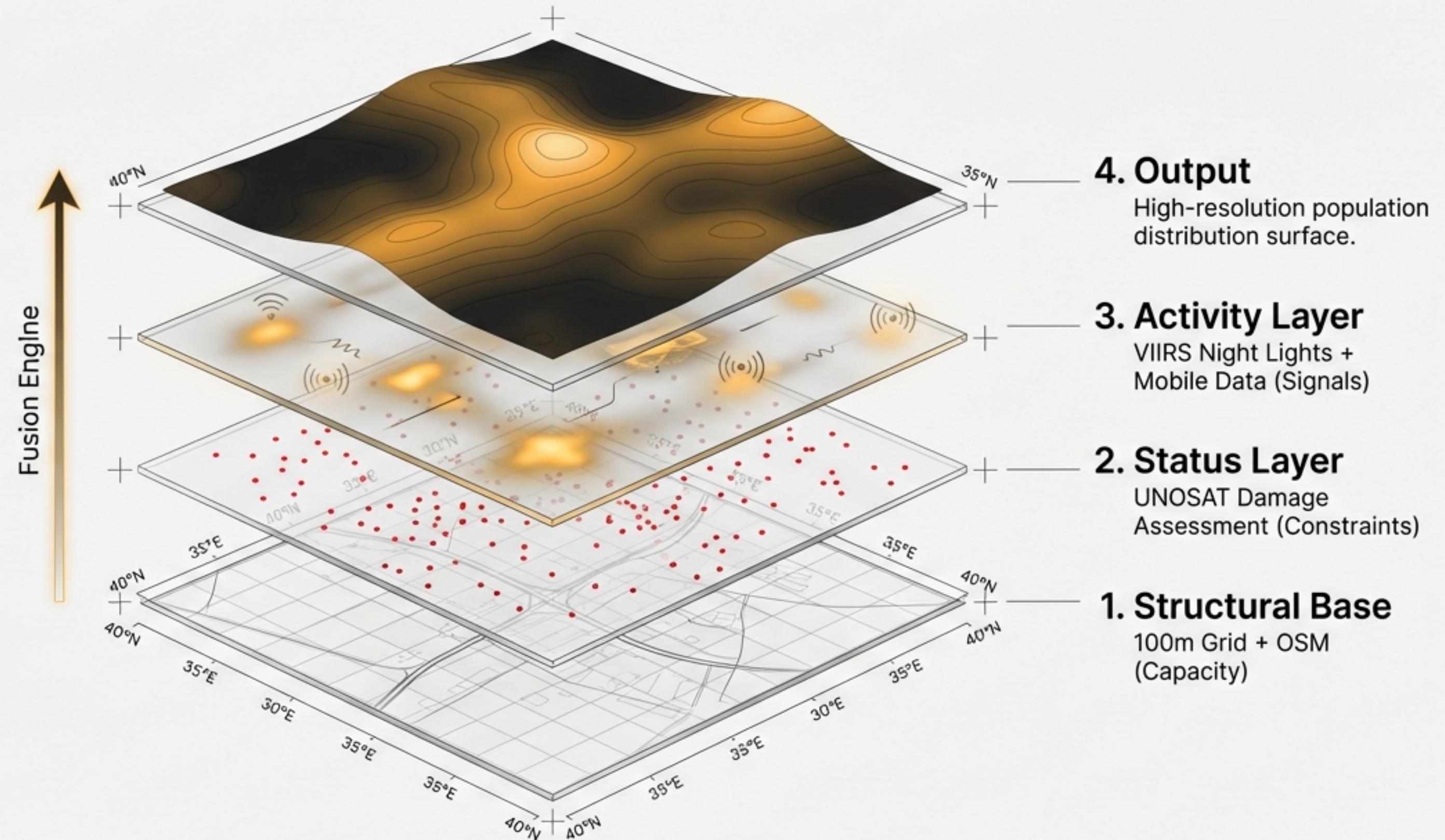


Remote Sensing: Dynamic, Remote, Real-time.

Insight: In extreme urban density and conflict, traditional census data is obsolete. We face restricted ground access, disrupted infrastructure, and rapid displacement.

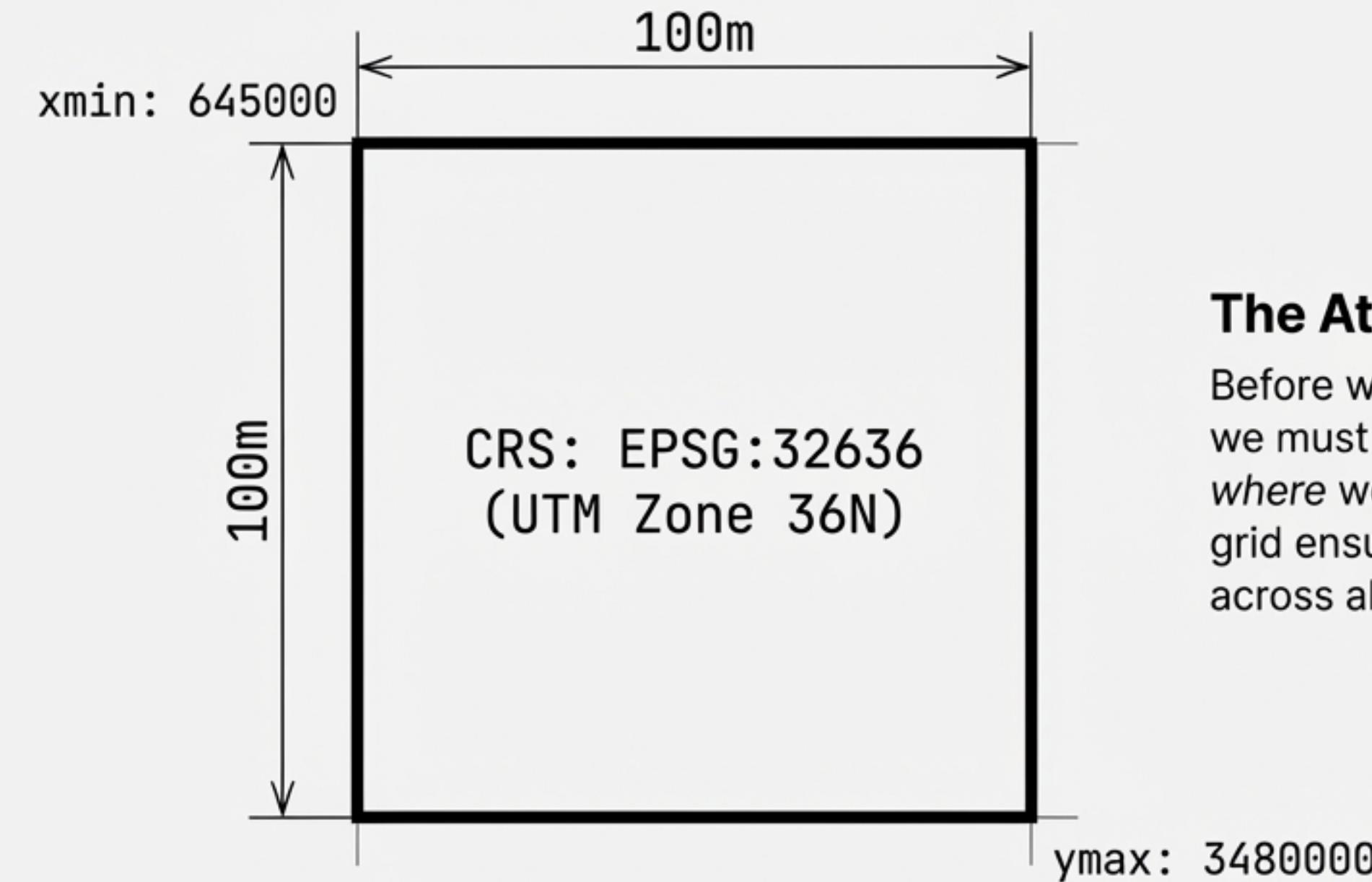
Objective: Calibrate relative population density in a highly dynamic environment.

The Integrated Estimation Workflow



Standardizing Space: The 100m Analysis Grid

Source: 01_make_grid_gaza_100m.R

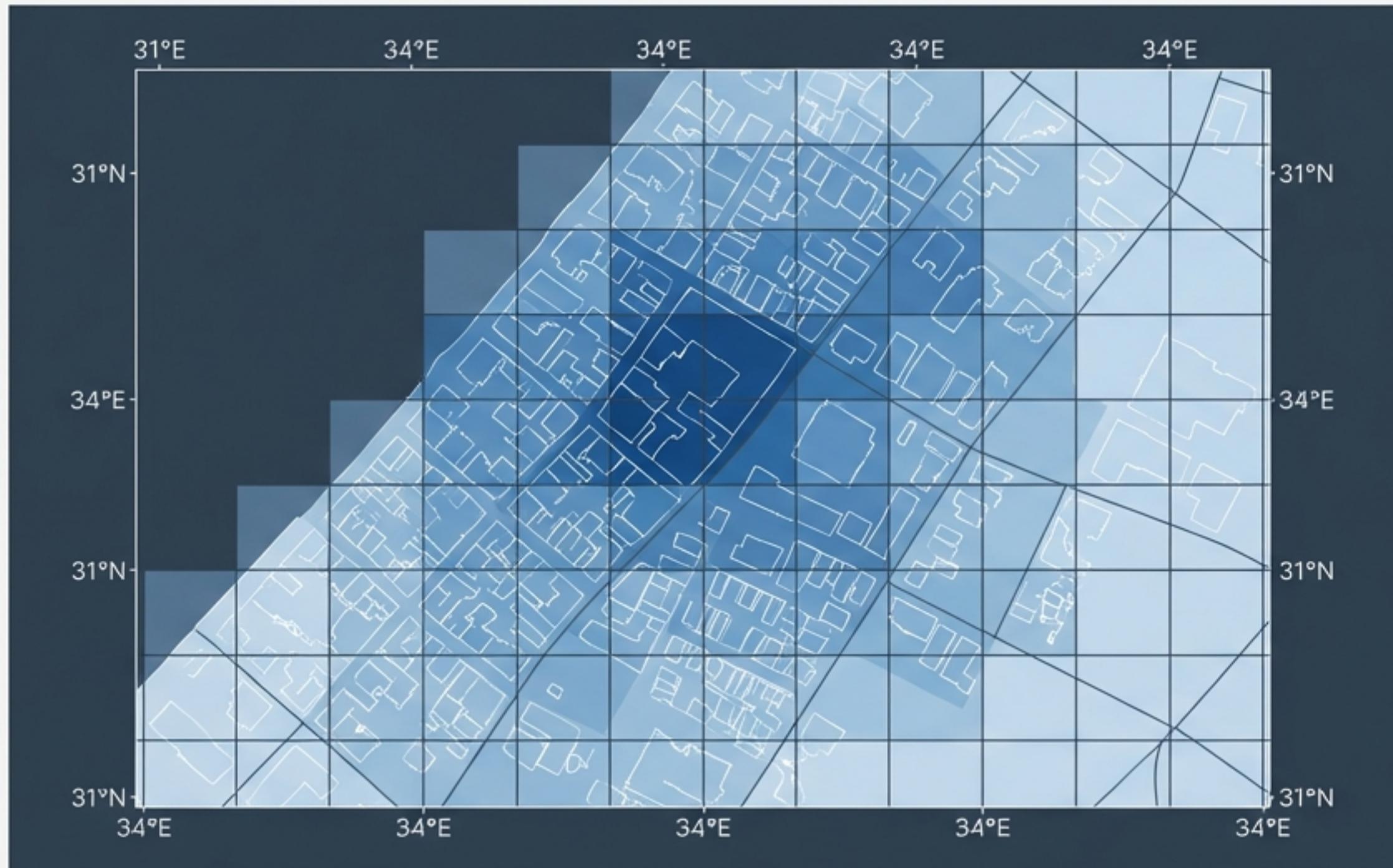


The Atomic Unit.

Before we measure who is there, we must mathematically define where we measure. The snapped grid ensures temporal consistency across all datasets.

Assessing Habitability Capacity (OSM)

Source: 02_osm_buildings.R



Input: OpenStreetMap (Overpass API)

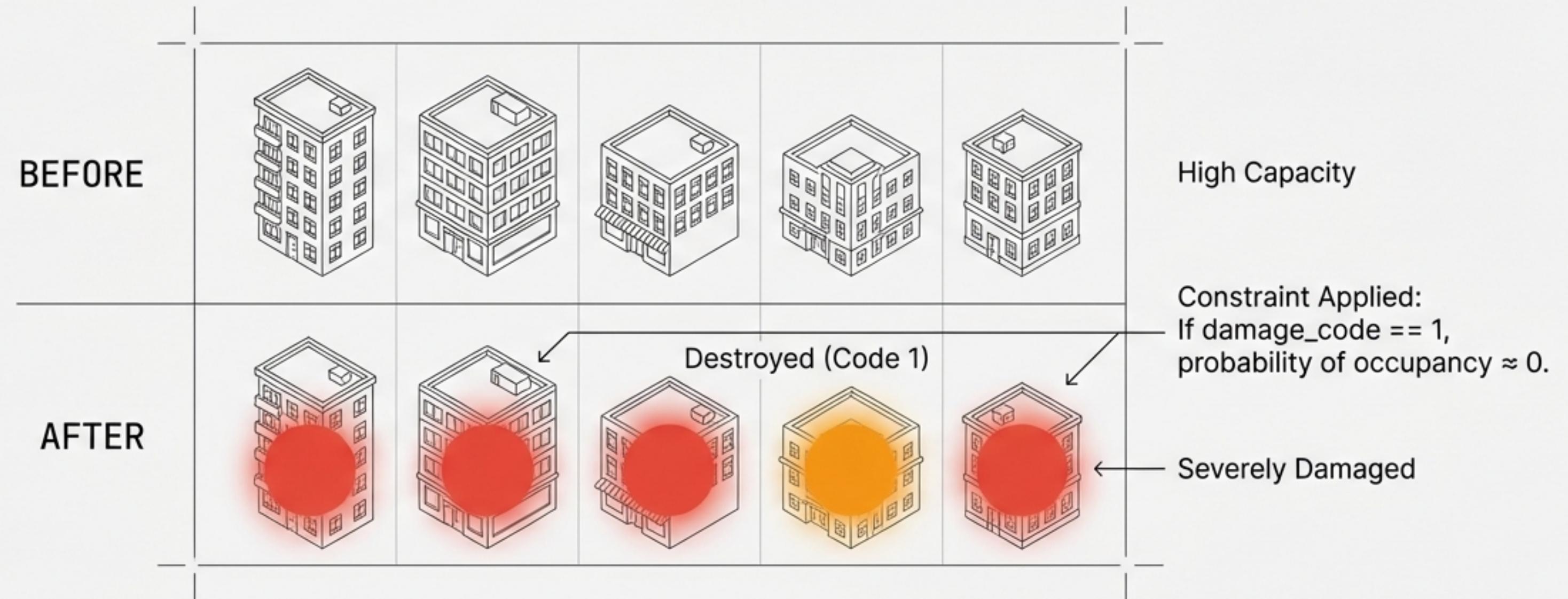
Calculated Metrics:

- dist_road_m (Accessibility)
- bldg_area_sum_m2 (Total Footprint)
- bldg_count_osm (Structure Count)

OSM data defines the potential maximum population capacity of a cell.

Accounting for Structural Loss

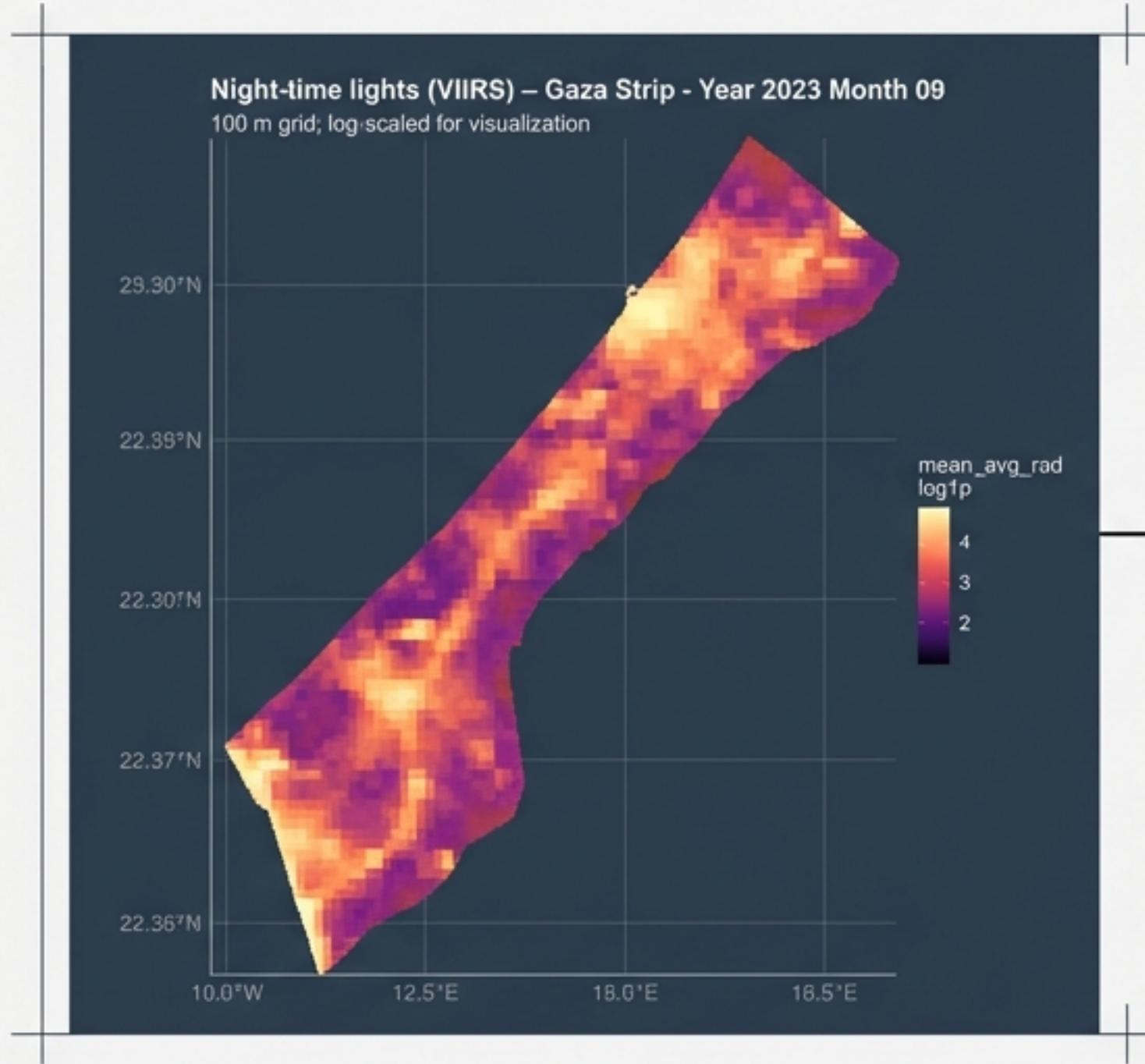
Source: 03_export_unosat_damage_csv.py



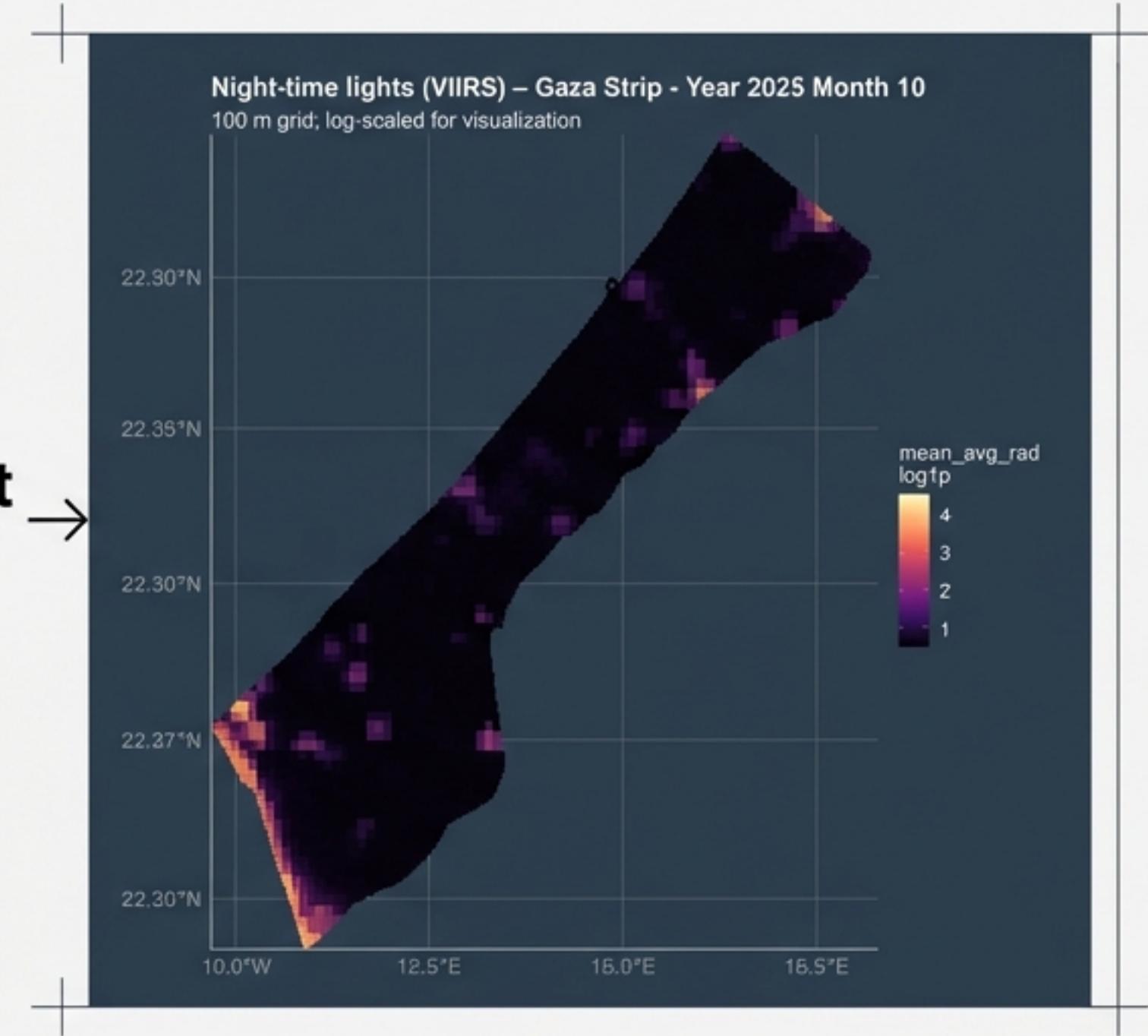
Population capacity must be discounted by damage.
A destroyed building houses no one.

Tracking Power and Human Activity (VIIRS)

JetBrains Mono | Source: 04_viirs_night_light.py



Blackout Effect →

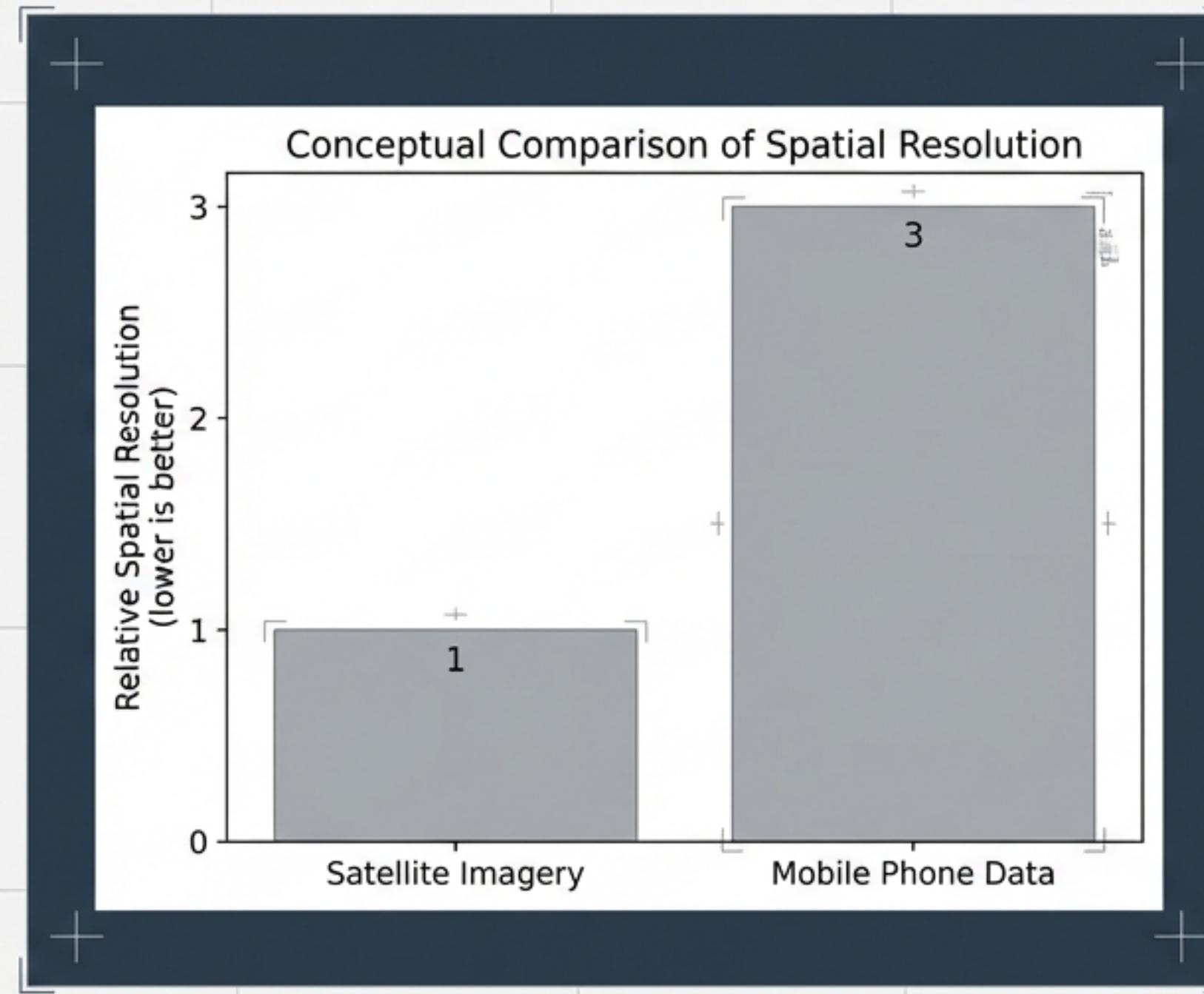


Metric: Monthly **mean_avg_rad** (log1p scaled).

The stark reduction in luminosity acts as a proxy for electrification and loss of activity.

Mobile Data: The Dynamic Pulse

Source: 05_mobile_data_comparison_chart.py



The Trade-off:

Satellite = High Spatial Resolution (100m), Low Frequency.

Mobile = Low Spatial Resolution (Tower level), High Frequency (Real-time).

While satellites show **where people can live**, **mobile data** (CDRs/Signaling) shows **where connected devices actually are**. It fills the gap by tracking flows and real-time displacement, despite coverage limitations.

Fusing the Signals

Source: 05_merge_grid_osm_unosat_viirs.R

The diagram illustrates the process of fusing signals. It begins with a 'Spatial Join' (indicated by a downward arrow) and then continues with an 'Attribute Merge' (indicated by another downward arrow). The resulting dataset is presented in a table.

cell_id	bldg_area (Capacity)	destroyed_n (Constraint)	mean_avg_rad (Signal)	mobile_sims (Signal)
12345	150.5 m ²	0	3.78	245
12346	210.0 m ²	2	1.12	480
12347	95.2 m ²	1	0.55	120
12348	180.3 m ²	0	4.01	310

This merged dataset allows us to query the intersection of existence (OSM), survival (Damage), and presence (Lights/Mobile).

From Data to Population Estimates

$$\text{Population} \approx f(\text{Structural Capacity} \times \text{Damage Factor} \times \text{Activity Signal})$$

Defined by **Satellite Built-up area.**

Inter JetBrains Mono

Discounted by **UNOSAT damage codes.**

Inter JetBrains Mono, **Alert Red.**

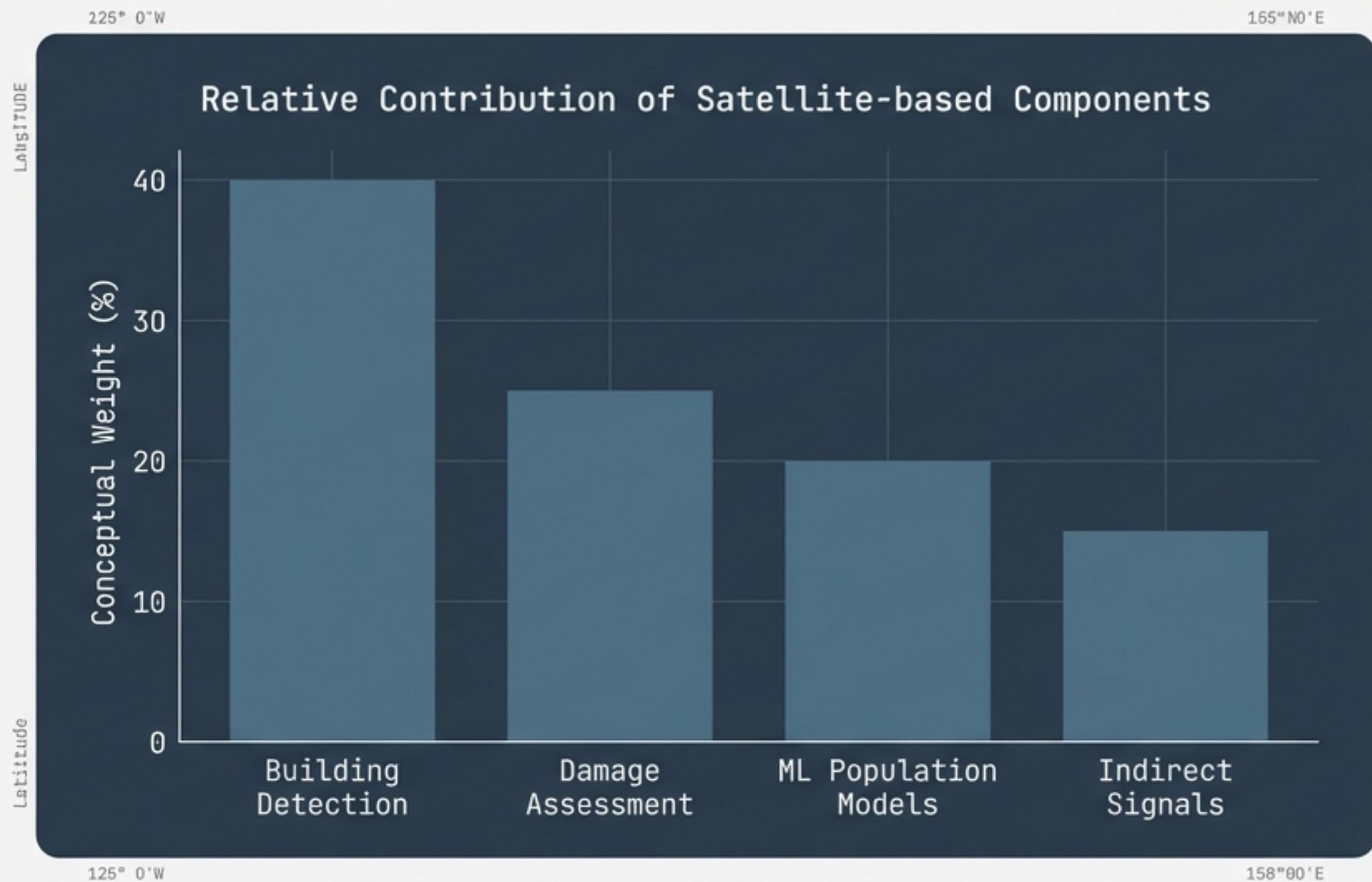
Modulated by **Mobile SIM counts + Night Lights.**

Inter JetBrains Mono **Signal Amber.**

Modeling Strategy: Machine Learning propagates “**Ground Truth**” densities to areas with similar signatures.

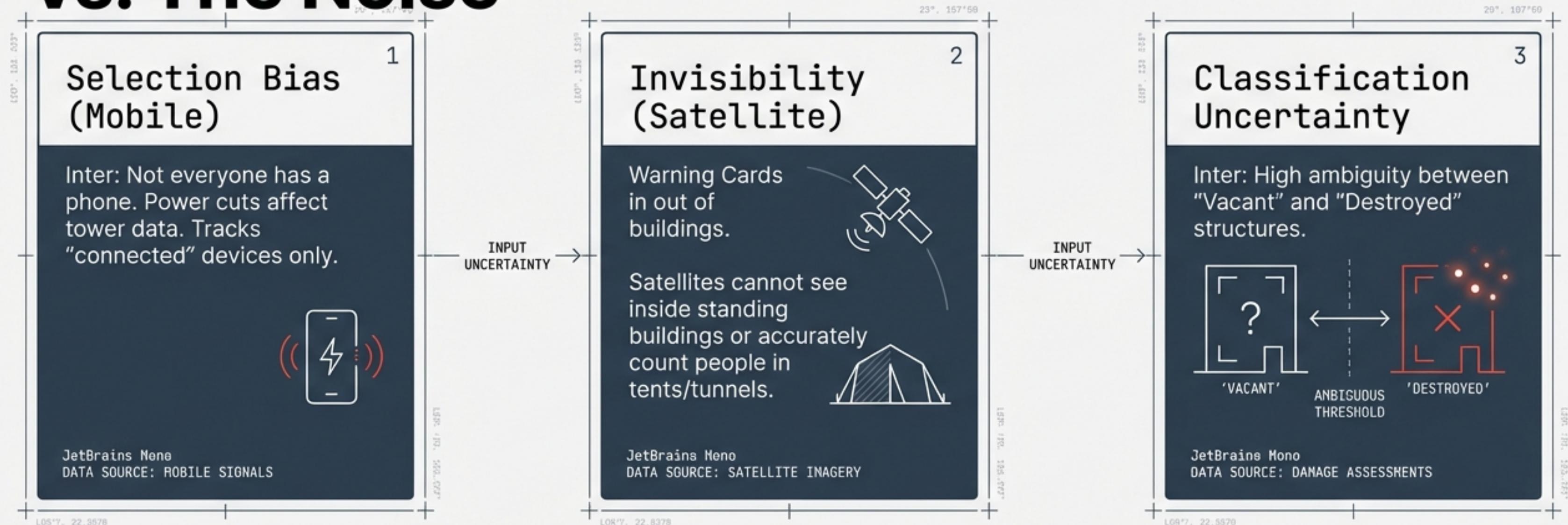
Inter

Weighting the Inputs



Structural detection remains the backbone. Indirect signals refine the estimate but cannot replace the physical map.

Interpreting the Signal vs. The Noise



"Mitigation: We model relative patterns, not absolute census counts." ← STRATEGY ADAPTATION

Data Ethics in Conflict Zones



Privacy

Aggregation is mandatory.
No individual tracking.



Do No Harm

Data is strictly for
humanitarian aid
prioritization, never for
targeting.



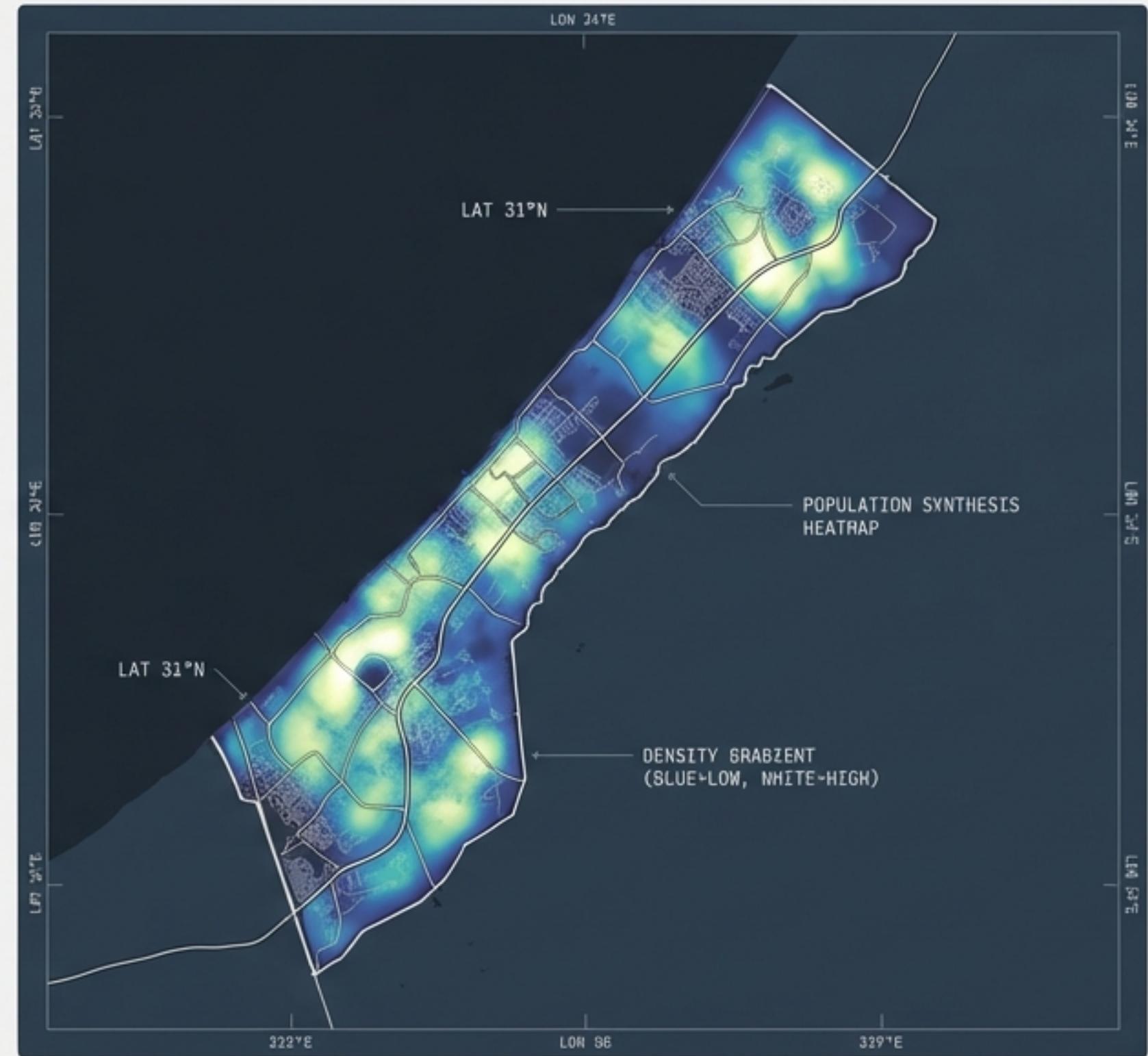
Transparency

Uncertainty must be
explicitly communicated
to decision-makers.

The Power of Converging Evidence

Key Takeaway: Neither satellite nor mobile data is sufficient alone. Together, they create a robust, uncertainty-aware map of displacement.

Final Thought: Robust relative patterns over precise absolute counts.



Workflow Tech Stack

R (Geospatial Core)

- `sf` (Simple Features)
- `data.table` (High-perf aggregation)
- `mapview` (Visualization)

Python (ETL & Earth Engine)

- `fiona` (GDB processing)
- `earth engine api` (VIIRS retrieval)
- `pandas` (Data manipulation)

Data Sources: OpenStreetMap, UNOSAT, NOAA/VIIRS, Mobile Network Operators.