Modeling urban systems: An under-explored research frontier

Research School of Earth Sciences
Australian National University
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Arizona State University
Outline for today’s talk

- Why study urban systems?
- Research problems in urban settings
- Arizona State University’s urban research agenda
- Tools for visualizing urban futures
Earlier geoscience research frontiers

- Oceans (ships)
- Atmospheres (aircraft)
- Planetary surfaces (spacecraft)
- Deep earth (seismology)
- Climate (satellites)
- Nanostructures (microscopy)
- Geobiology (genomics)

New frontiers depend on new observations
They offer opportunities for societal relevance
Why have an urban system science research agenda?

- More than half of the world’s population lives in cities
- World’s urban infrastructure must double in 35 years
- Little science input on how to make cities sustainable
- Climate change driven increasingly by urban activities
- Urban impact growing on all undeveloped lands
- Decision-making process not understood scientifically
What are some key urban system science questions?

- How does the growth of cities affect global climate?
- What factors control urban “ecological footprints”?
- How do spatial variations in pollution affect health?
- How does land cover change affect biogeochemistry?
- Can urban energy flows be accurately modeled?
- How can cities most fully recover from disasters?
Who will fund the coordinated study of urban systems?
Who will fund the coordinated study of urban systems?
Why study urban systems in Phoenix?

- 5th largest, 2nd fastest-growing city in USA
- Geography, climate, hydrology, history easy to model
- Several large federal environmental research projects
- Global relevance: heat island, drought, mass migration
- Academic-government partnerships seeking to make Phoenix a wired, modeled lab for rapid urbanization
What are key boundary conditions for modeling Phoenix?

- Spatial: *city strictly limited by infrastructure*
- Population: *well documented, rapid growth*
- Cultural: *built along Hohokam canals (AD 1000)*
- Topography/Tectonics: *Basin and Range, stable*
- Water: *canals, reservoirs, streams, groundwater*
- Air: *eastward flow, “heat island”, “brown cloud”*
- Land Use: *desert → agriculture → urban*
- Economy: *mining/agriculture → high tech/tourism*
Laboratory domes mimic urban growth?

High eruption (population growth) rate
Low cooling rate (housing prices)
Arizona State University

- Fifth largest university in U.S. (~ 62,000 students)
- Four campuses in metro Phoenix
- Rapid recent growth; NAS/NAEs from 3-13 in 4 years
- Founded in 1885; first PhD not until 1963
- 1 of 8 “Research 1” Universities w/o Med or Ag School

*Focus on interdisciplinary research that is socially-relevant, use-inspired, globally engaged*
What are ASU’s urban research assets?

- CAP-LTER, one of two Urban LTERs
- Two Urban Ecology IGERTs (NSF)
- Agrarian-urban transitions (NSF)
- Decision Center for a Desert City (NSF)
- Nat Ctr Excel. in SMART materials (EPA)
- Urban Fluid Dynamics (ADEQ, EPA)
- Greater Phoenix 2100 Project
- 100 Cities remote sensing (NASA)
- Morrison Institute for Public Policy
- Center for Science, Policy & Outcomes
CAP is one of only two Urban LTERs

*LTER network allows cross-site comparisons*

**Phoenix**
- young city
- rapid growth
- arid climate
- rugged topography

**Baltimore**
- old city
- slower growth
- humid climate
- flat terrain
Underlying CAP-LTER research questions

How does urbanization alter city’s ecological context?
How does ecological context affect urban development?
CAP-LTER 200 Point Survey

Uniform data collected regularly

50 km
CAP-LTER

Spatial Context

- CAP ecosystem in global context
- CAP ecosystem in regional context
- Whole-system measures
- Interactions among patches
- CAP ecosystem as a landscape
- Within-patch studies
- Comparison of patch types

* EF with trade
  Budget comparisons

* Ecological footprint
  Fate of NOx

* N, C mass balances
  Atmospheric deposition
  Surface water in/outputs

* Materials transport
during storms
Recipient systems

* Nutrient storage and transformation
Biogeochemistry of aquatic ecosystems

Increasing scale
Analyze complex human impacts on cities

• Hydrologic modifications
  – Land cover changes
  – Manipulation of water source, amount, quality
  – Simplification of flowpaths

• Chemical modifications
  – Enhanced N, C deposition
  – Addition of novel compounds and pollutants
Comparing Urban and Desert N Budgets

**Phoenix Ecosystem**

- **N input**: 76.2
  - NOx from combustion: 37%
  - Imported N: 53%
  - N fixation & deposition: 10%
- **Riverine export**: 2.1 (2.8%)
- **Gaseous output**: 57.8 (75.6%)
- **Accumulation**: 14.3 (18.7%)
  - (10.5 by summing fluxes)
- **Milk and meat**: 2.0 (2.6%)

**Desert Ecosystem**

- **N input**: 5-20
  - N deposition: 20%
  - N fixation: 80%
- **Riverine export negligible**
- **Gaseous output near 100%**
- **Internal recycling >>100%**

units: kg/ha

Increase in fertilizer use occurred simultaneously with population growth...

Today, NO₃ concentration increases along canal flowpaths as NO₃-enriched ground-water is pumped into canal for agricultural uses.
Improved land cover classification leads to improved weather forecasts

MM5 (USGS 25 m topography)       Actual (AVHRR)

Temperature forecasts improve by 2 degrees C

Will Stefanov, ASU
48 Hr MM5 surface temperature forecast

Urban and rural sites are under predicted

Daytime part of cycle now okay
Heat island effect still absent
Urban heat island effect

In 2006, Phoenix had the hottest June on record, but public thought it was relatively cool.
Greater Phoenix has experienced continual nighttime temp increases in comparison to a rural control site.

<table>
<thead>
<tr>
<th>Year</th>
<th>Airport Day</th>
<th>Airport Night</th>
<th>Downtown Day</th>
<th>Downtown Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>+2</td>
<td>+6</td>
<td>-4</td>
<td>+5</td>
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<tr>
<td>2000</td>
<td>+4</td>
<td>+12</td>
<td>-2</td>
<td>+10</td>
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</tbody>
</table>
ASU-PHX study of Airport thermal footprint

Sky Harbor Airport
Effects of urbanization and climate change

UHI effect may be 15-30°C
Urban fluid dynamics program

- Measures/models multi-scale urban air flows
- Analyzes pollution for Ariz. Dept. of Env. Quality
- Links to County’s public health studies
- Homeland security dispersion applications
- Supported by NSF, EPA, ADEQ, ADOT
Pollution in Complex Terrain

Phoenix

Salt Lake City

Los Angeles

Hong Kong
Phoenix Brown Cloud

Purple haze, unhealthy days

From the Arizona Republic
Chemical Spills

Hazardous cloud
Crews contain acid leak in Laveen; 200 residents evacuated

From the Arizona Republic
Growth and breakdown of El Paso inversion layer
Flows in urban airsheds

- **Synoptic Flow**
- **Katabatic (downslope)**
- **Anabatic (upslope)**
- **Thermal circulation**
Lab modeling of cold pool destruction
Lab modeling of cold pool destruction

Run 19 - Thermally Stratified

See Run19-temp.avi for Temperature Profiles
Variations in temperature stratification
City-Scale Models: Phoenix
City-Scale Models: Oklahoma City
100 Cities Project: Standardized, repeated urban remote sensing

Partners

- **Existing**
- **Negotiating**
- **Planned**
100 Cities Project:

- Annual day and night images collected for each
- Goal is to partner with local groups in all 100 cities
- Can we develop a taxonomy of growing cities?
- How can cities minimize their environmental impact?
- How can urban security threats be minimized?
- How can technologies promote sustainability?
Steps to Regional Decision-making

1. Ask community for input
2. Agree about what’s important
3. Find and get the needed data
4. Analyze data using different models
5. Use models to forecast the future
6. Use forecasts to inform policy decisions

The process involves a cycle of decision-making steps, starting with community input and ending with making decisions that inform the community.
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Policy
Science
Greater Phoenix 2100 - Goals

• Develop **visualization tools** to help policy-makers better understand implications of their decisions

• Make science and engineering results more accessible

• Promote regional and long-term perspectives

• Partner with businesses and state agencies
Greater Phoenix 2100

Visualization tools

- Regional e-Atlas
- SIM Phoenix
- Decision Theater
- Urban-SAT(s)

Electronic version linked to original data
Table 2: Scenarios For Future Growth of Greater Phoenix

<table>
<thead>
<tr>
<th>Year</th>
<th>Scenario 1: Annualized Growth Rate Over the Last 50 Years (4.4%)</th>
<th>Scenario 2: Lowest Annualized Growth Rate of Any Single Decade of the Last 50 Years (3.4%)</th>
<th>Scenario 3: Lowest Annualized Growth Rate of Any Single Decade of the Last 100 Years (2.2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>3,251,876</td>
<td>1,207</td>
<td>3,251,876</td>
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<tr>
<td>2010</td>
<td>5,009,144</td>
<td>1,859</td>
<td>4,549,622</td>
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<td>2020</td>
<td>7,716,016</td>
<td>2,864</td>
<td>6,365,269</td>
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<tr>
<td>2030</td>
<td>11,885,644</td>
<td>4,411</td>
<td>8,905,496</td>
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<td>2040</td>
<td>18,308,480</td>
<td>6,795</td>
<td>12,459,468</td>
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<tr>
<td>2050</td>
<td>28,202,126</td>
<td>10,467</td>
<td>17,431,745</td>
</tr>
</tbody>
</table>

How fast will Metro Phoenix grow?
Maps combine many data sets

Continuous updates of on-line versions

Data shared by many agencies

How to preserve most desirable areas?
Greater Phoenix 2100

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- SIM Phoenix
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Model the future of the region

Tempe Town Lake
Model the entire urban system

Forecasting models link water, energy, air, land use, solid waste, and transport aspects of urban systems
Greater Phoenix 2100

Visualization tools

- Regional e-Atlas
- SIM Phoenix
- Decision Theater
- Urban-SAT(s)

A place to convene decision-makers
Decision Theater: Current Projects

Water supply and demand

Infrastructure planning

Urban heat island

Tracking air pollution
Forecasting water supply & demand

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<th>Sponsor</th>
<th>Objective</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Center for a Desert City, National Science Foundation</td>
<td>Developing a Comprehensive Water Model for Phoenix</td>
<td>System Dynamic Simulation Model; GIS</td>
</tr>
</tbody>
</table>

**Credit**: Dr. Tim Lant, Decision Center for a Desert City
Greater Phoenix 2100

Visualization tools

- Regional e-Atlas
- SIM Phoenix
- Decision Theater
- Urban-SAT(s)

*Instruments customized for urban monitoring*