China’s urbanization and its sustainability under future climate change

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Research Background

- **Rapid urbanization in China after the reform**
  - before: strict control through household registration;
  - after: eco development & rural-urban migration
- By the end of 2011, urbanization reached over 50%
- => Urban sprawl
- => Degradation of urban environment
- Gaps: climate & its impact at local scale, adaptation, mitigation
Research Objectives:
(1) to analyze the causal linkages between urbanization, urban sprawl (LCLUC), and climate change
(2) to simulate LCLUC and local scale IPCC climate scenarios and to evaluate current adaptation strategies and provide adaptation recommendations to urban policy makers on various LCLUC and future climate scenarios

Project:
--- 3 year duration (2009-2012) + no cost extension
--- 2 case cities: Shanghai and Urumqi
--- Team members from various disciplines: social science, urban planning, geography, climatology, etc
--- Collaborators in Shanghai and Urumqi
Objective 1

• **Urbanization and LCLUC**
  
  – Shanghai:
    
    • Urbanization, urban sprawl, & urban land transformation at district level
    • urban land use changes by different types
    • urban industrial land and its spatial determinants
  
  – Urumqi:
    
    • Urbanization, urban sprawl, degraded urban environment
    • Develop LULC maps, focusing on agriculture & urban expansion
    • Uncertainty model for MODIS land cover type products and its propagation to RAMS
Shanghai

- General
  - A globalizing city
  - largest economic center since 1850
  - manufacturing center during Maoist period (1949-78) (>70% of output)
  - transition to tertiary sector
  - international prominence

- Urbanization
  - 59% (1978) => 86% (2007)

- Urban sprawl
  - Expanded 38 times:
    - 76 (1947) to 2911 km² (2010)
  - Expanded almost 6 times

Source: Yue et al, 2010; Fan et al, 2012
Urban expansion pattern (2000-2010)

Legend
- Research area
- Water body
- Non-urban area
- Urbanized area in 2000
- Urbanized area from 2000-2005
- Urbanized area from 2005-2010

Approx. urbanization direction of 2000

16 Directional sectors
Percentage of urban land

- 1683 km² → 2883 km²
- More intensive 2000 - 2005
- Mainly at existing urban areas, industrial zones, or planned areas
- Directional and uneven (NW-SE axis)
**Shanghai Land Conversion Matrix**

- 2000-2005: Farm land was the dominant source for urban & industrial land conversion
- 2005-2010: Farm land remained to be the largest source, but urban ↔ industrial were also significant

<table>
<thead>
<tr>
<th></th>
<th>2005 Total</th>
<th>2000 Total</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Industrial</td>
<td>Transportation</td>
</tr>
<tr>
<td>Industrial</td>
<td>275.07</td>
<td>11.55</td>
</tr>
<tr>
<td>2000 Transportation</td>
<td>26.26</td>
<td>119.05</td>
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<tr>
<td>Urban</td>
<td>86.31</td>
<td>21.93</td>
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<tr>
<td>Green Land</td>
<td>15.80</td>
<td>6.10</td>
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<tr>
<td>Farm</td>
<td>254.28</td>
<td>50.10</td>
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<tr>
<td>Water</td>
<td>31.84</td>
<td>12.82</td>
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<td>2005 Total</td>
<td>689.55</td>
<td>221.55</td>
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<table>
<thead>
<tr>
<th></th>
<th>2010 Total</th>
<th>2005 Total</th>
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<tbody>
<tr>
<td></td>
<td>Industrial</td>
<td>Transportation</td>
</tr>
<tr>
<td>Industrial</td>
<td>416.86</td>
<td>0.53</td>
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<td>2005 Transportation</td>
<td>0.36</td>
<td>158.08</td>
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<tr>
<td>Urban</td>
<td>144.92</td>
<td>45.71</td>
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<tr>
<td>Green Land</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Farm</td>
<td>137.62</td>
<td>48.42</td>
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<tr>
<td>Water</td>
<td>23.72</td>
<td>8.65</td>
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<td>2010 Total</td>
<td>723.48</td>
<td>261.40</td>
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</table>
Shanghai – Urban land use by types:

- *residential* - continuous growth
- *industrial* - declined 1993-2003
  relocation of factories
- *commercial* - climbing due to
  increased infrastructure investment,
  urban redevelopment

Key factors?

- Land market reforms
- migration
- preferential policy
  - uneven distribution of
    foreign direct investment (FDI)
  - Economic development zones
- phases of economic transition, restructuring
- role of the multi-scaled state, governance
Shanghai –
Evolution of urban industrial land

first increased rapidly 1947 - 1984, then started decreasing from 1993

a hybrid monocentric pattern => a specialized polycentric pattern

Source: Fan et al, 2011
Shanghai – spatial determinants of urban industrial land conversion (2002-2009)

Major spatial determinants: land price, existing industrial land, land policy
LCLUC at district level, 2000 – 2010

Suburban districts
- noticeable urbanizations

City core districts (red oval)
- relative intensive urbanizations were taking place (Putuo, Changning)
- city planning: urban redevelopment, industry reallocation

Chongming (blue oval)
- high absolute urban land
- relative low urbanized rate
- Ecological land (2005)
Suburban low-density industrial zone

Redevelopment at old urban district

Rising new CBD in Lujiazui, Pudong
Case 2: Urumqi – urbanization and urban sprawl

Urumqi, Capital of Xinjiang Uyghur Autonomous Region
- important trading center for centuries
- military base
- westward migration - factor in industrialization

Urumqi today...
- exponential economic growth 1990s onward
- investment in energy industry
- new growth in tertiary sector
- Int’l trade with Russia, tourism

Urban Land conversion
- 38 km$^2$ in 1963,
- 238 km$^2$ in 1990
- 381 km$^2$ in 2010
Urumqi: degraded urban environment from urbanization/industrialization

**Urban air pollution**
- one of the top ten most polluted cities in the world (WHO, 1998)
- soot and dust from coal, combined with location in the valley of Tianshan Mountain; it is getting better

**Water resources & consumption**
- scarce, severely polluted -- available water per capita is ¼ of the national average
- human impacts – overgrazing, industrialization, urbanization

**Cautionary tale for urbanization** --
- over-dependence on industries based on fossil fuel resources can lead to rapid economic development, with unintended consequences
High rise condominiums (left), government buildings (up right), and residential houses (lower right) burn coals for heating. Photos were taken by Dr. Qingdong Shi at Xinjiang University, Urumqi, China, on Jan. 30, 2009.
Urumqi: Develop LULC maps focusing on Agriculture & Urban Expansion

• used GLS / Landsat TM time series to map LULC in 1975, 2000, and 2010

• integrate Landsat TM & ALOS PALSAR to map urban and assess LCLUC to 2010

• Preprocessing streams for data =>

• Approach used a CART

• Post processing applied operational thresholding of Landsat, PALSAR, and Aster DEM indices to adjust products
Objective 2

• Simulation of future LCLUC and regional climate changes, impact of climate change, and adaptation and mitigation strategies
  – 2a. Simulation of current and future LULC
  – 2b. Regional climate simulation under IPCC scenarios
  – 2c. Impact of climate change on cities
  – 2d. Adaptation and mitigation strategies
Objective 2a. Simulation of current and future LCLUC

- **Shanghai**: CLUE-S modeling for future land use scenarios
  - Reclassified land use data of 2000: a background start year
  - Identifying driving factors: inputs
  - 2020 Year’s planning map: a target demand of land use
Dyna-CLUE: driving factors

\[
\log\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_n X_{ni}
\]

Where:
- \(P_i\) is the probability of a grid cell for the occurrence of the considered land use type on location \(i\);
- \(X's\) are the location factors.

<table>
<thead>
<tr>
<th>var.</th>
<th>intercept</th>
<th>dem</th>
<th>slope</th>
<th>city</th>
<th>road</th>
<th>water</th>
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<tbody>
<tr>
<td>estimates</td>
<td>3.880e+00</td>
<td>-1.211e-03</td>
<td>-1.518e-01</td>
<td>-5.710e-05</td>
<td>-8.680e-05</td>
<td>5.385e-05</td>
</tr>
<tr>
<td>(D^2)</td>
<td>0.4678</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Signif. codes: 0 ‘***’ 0.001  \(D^2 = 1-(\text{residual deviance/null deviance})\)
Clue-s Simulations (2000-2020)

---Contributing factors for Urban Land Presence

---Three Scenarios

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Description</th>
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<tbody>
<tr>
<td>Base</td>
<td>Urbanization occurs with a linear growth rate with no specific protection of urban green land</td>
</tr>
<tr>
<td>Unrestricted</td>
<td>Urbanization occurs with a decelerating growth rate (nonlinear) and with no specific protection of urban green land</td>
</tr>
<tr>
<td>Restricted</td>
<td>Urbanization occurs with a decelerating growth rate (nonlinear) and with specific protection of urban green land</td>
</tr>
</tbody>
</table>
b) Clue-s Simulations (2000-2020)

Figure 4: LUCC Simulations for 3 Scenarios

- Green land well preserved in the restricted scenario
- More urbanization before 2010 in the unrestricted (deceleration) and restricted scenarios
- Some satellite towns are connected to the existing urban core while new ones are emerging (Fenxian, Jinshan)
Landscape Feedbacks

Figure 5: Selected Landscape Metrics Responses of Scenarios

- The deceleration and restricted scenarios: the same patterns for land metrics LPI and SHDI
- The restricted scenario—the most complex landscape
- The deceleration scenario—the most aggregated landscape.
- SHAPE_MN decreases in all scenarios, but increases for the restricted scenario after 2004.
Urumqi Land use change simulation

• Land use demand
  – Balanced scenario: historical trend extrapolation for both urban and agricultural land

![Land use change trend graph](image)
Dyna-CLUE: simulation results

<table>
<thead>
<tr>
<th>From\To</th>
<th>Balanced</th>
<th>Farmland preservation</th>
<th>No restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>56220.8</td>
<td>56220.8</td>
<td>56220.8</td>
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<tr>
<td>A</td>
<td>4078.44</td>
<td>1118.88</td>
<td>7077.6</td>
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<tr>
<td>LV</td>
<td>5335.56</td>
<td>8232.48</td>
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<tr>
<td>HV</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>W</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</table>
2b Regional climate simulation under IPCC scenarios

• Several regional climate model (RCM) simulations: underway.
• Investigate potential changes in land cover (particularly degradation) on overall atmospheric dynamics—convection, wind speed, rainfall, and near-surface humidity.
• These simulations, at 2 km resolution, are expected to test whether or not recent trends in land cover change will act to suppress growing-season rainfall or not.
• How urban expansion will affect these variables under climate change (input from the LCLUC simulations), project impacts out to 2050.
• Challenges: numerical stability in the RAMS code; Error propagation from land cover parameterizations.
Urumqi - understanding environmental change: Modeling Climate

incorporate land use in Regional Atmospheric Modeling System (RAMS) 6.0
MODIS albedo, NDVI variables added directly into land surface model

Preliminary results

- previous work shows region will experience higher temperatures, and thus, increased threat of desertification
- changes in fractional vegetation cover - models show higher wind speeds may better disperse pollutants; may lead to better air quality

Multiple nested grids (2 and 8 km shown) of the RAMS model, and aggregated land cover classes
Urumqi: Uncertainty of MODIS Land Cover Type (MLCT) product

<table>
<thead>
<tr>
<th>Year</th>
<th>MODIS Land Cover Codes</th>
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<tbody>
<tr>
<td>2001</td>
<td>6-Closed shrublands</td>
</tr>
<tr>
<td>2002</td>
<td>7-Open shrublands,</td>
</tr>
<tr>
<td>2003</td>
<td>8-Woody savannas</td>
</tr>
<tr>
<td>2004</td>
<td>10-Grasslands,</td>
</tr>
<tr>
<td>2005</td>
<td>12-Croplands</td>
</tr>
<tr>
<td>2006</td>
<td>16-Barren or sparsely vegetated</td>
</tr>
<tr>
<td>2007</td>
<td></td>
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<tr>
<td>2008</td>
<td></td>
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Trajectory analysis

Categorical uncertainty

<table>
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<th>MODIS Code</th>
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<th>7</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>16</th>
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<tbody>
<tr>
<td>6</td>
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<td>10</td>
<td>+</td>
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<td>16</td>
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</table>

+++very high, ++high, +moderate, -low
Uncertainty propagation through RAMS

- a “binary control model” to create dozens of land cover realizations (variation in land covers caused by detected uncertainty)
  - assume equal possibility of two land cover types if a change between “suspicious pairs” occurs.
  - the land cover realizations => RAMS
  - analyze the RAMS results to study the potential impact of uncertainty from MLCT products.

MLCT 2004

Land cover data

Uncertainty model

Land cover realizations

RAMS

Outputs

Binary control model

Study year

Croplands

Detected change

Grasslands

Previous year

Study year

Croplands

Binary Control

on

off

Study year

Grasslands
Urumqi Land use change simulation

- dyna-CLUE model

Climate: Impact on climate of uncertainty associated with misclassification of land cover

Figure. Uncertainty in Sensible Heat Flux (W/m²) due to classification error =>

Changes in land cover will have an impact on albedo, fractional cover, and other biophysical characteristics that will in turn affect the surface energy budget and atmospheric dynamics.

64 maps of Urumqi land cover have been imported into RAMS and are being simulated at a 2km grid spacing (expected to be complete in July)
2c Impact of climate change on cities & 2d Adaptation and mitigation strategies
- Changing climate in Shanghai

- max temp increases 1949-2007, summer gets hotter
- min temp increases 1949-2000, warmer winters
- ongoing work links land use to climate change using regional climate models
Future climate - Shanghai

• Statistical downscaling method

• an obvious shift in mean temperature in urban center
  • a 1.2°C shift in average July temperatures
  • consistent with a mid-century A1B trend

• Will apply the methodology for larger areas (analysis underway)
  • expected to show longer “tails” on the distribution,
  • indicating a likelihood of more extremely hot days
2c Impact of climate change on cities & 2d Adaptation and mitigation strategies

--- Urban Heat Island in Shanghai

- change in intensity of thermal environment at the urban core
- spread of heat island effects to periphery

**Findings** - leading factors contributing to the urban thermal environment
- land surface modification,
- landscape configuration
- anthropogenic heat release

Shanghai’s urban thermal environment (unit: °C) (L: 2000, R: 2008)
Summary

• Integrated system
  – Urbanization, LCLUC, urban environment change and climate change, socio-economic driving force
• Multi-scale: metro, urban built-up, district, street
• Temporal: past, current, future
• LCLUC
  – Urban sprawl ++
  – Different dynamics of different types of urban land (e.g., ind. Land)
  – Spatial determinant
  – Land simulations & policies
  – Urban China in a transitional economy: spatial policy + market force
• Climate Change
  – Uncertainty propagation
  – RCMs: Contribution of LCLUC to CC
  – Microclimate: significantly affected by landscape configuration

Spatial policy plays a critical role: Urban Planning Museums of Shanghai (top) & Urumqi (down)
Outcomes

• Invited report for the Asian Development Bank (ADB) – Project of “Urbanization in Asia”
  – The challenge of urban sustainability: Urban sprawl in Asian cities
• Peer reviewed journal papers
• Book chapters
  – 2012: The Urban Expansion and Sustainability Challenge of Cities in China’s West: The Case of Urumqi
  – Forthcoming: Urban Expansion and Environment Change in Dryland East Asia
• Conference presentations
  – About 10 presentations at various international/national venues, e.g., AAG, AGU, ACSP, GLP
• A new graduate level course at MSU
  – UP800: Urban Sustainability and Climate Change: An International Perspective
• Work (journal papers) in progress:
  – Modeling urban change in Urumqi, China
  – Urban expansion, landscape pattern, and land conversion in a transitional economy: the case of Shanghai
  – Exploring land use /land cover change pattern in Shanghai with CLUE-s simulation
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• Guanghui Lv & Qingdong Shi (Xinjiang University, Urumqi)
• Bin Zhao (Fudan University, Shanghai)
• Anxin Mei (East Normal University, Shanghai)