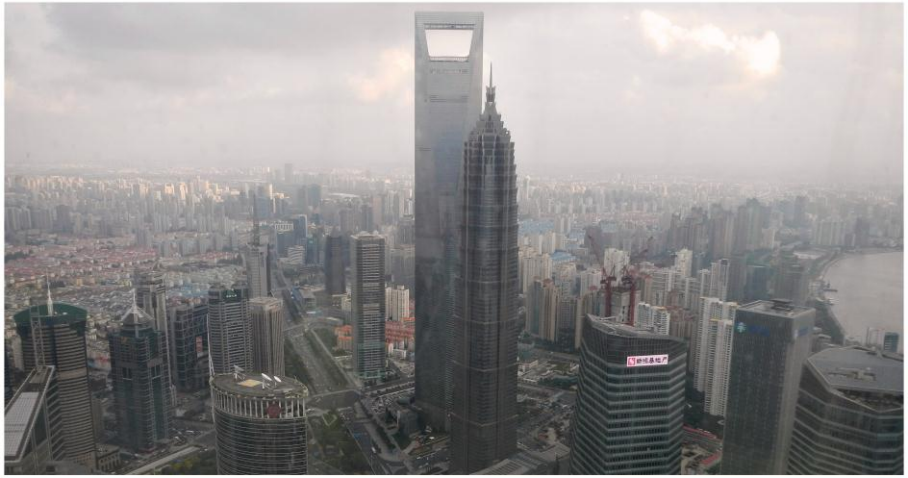
China's urbanization and its sustainability under future climate change



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Huiqing Huang (Michigan State U)

Grant #: NNX09AI32G

Peter Verburg

Wenze Yue

Huiqing Huang

Michelle Li

Nathan Torbick

William Salas

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

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

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

Objective 1

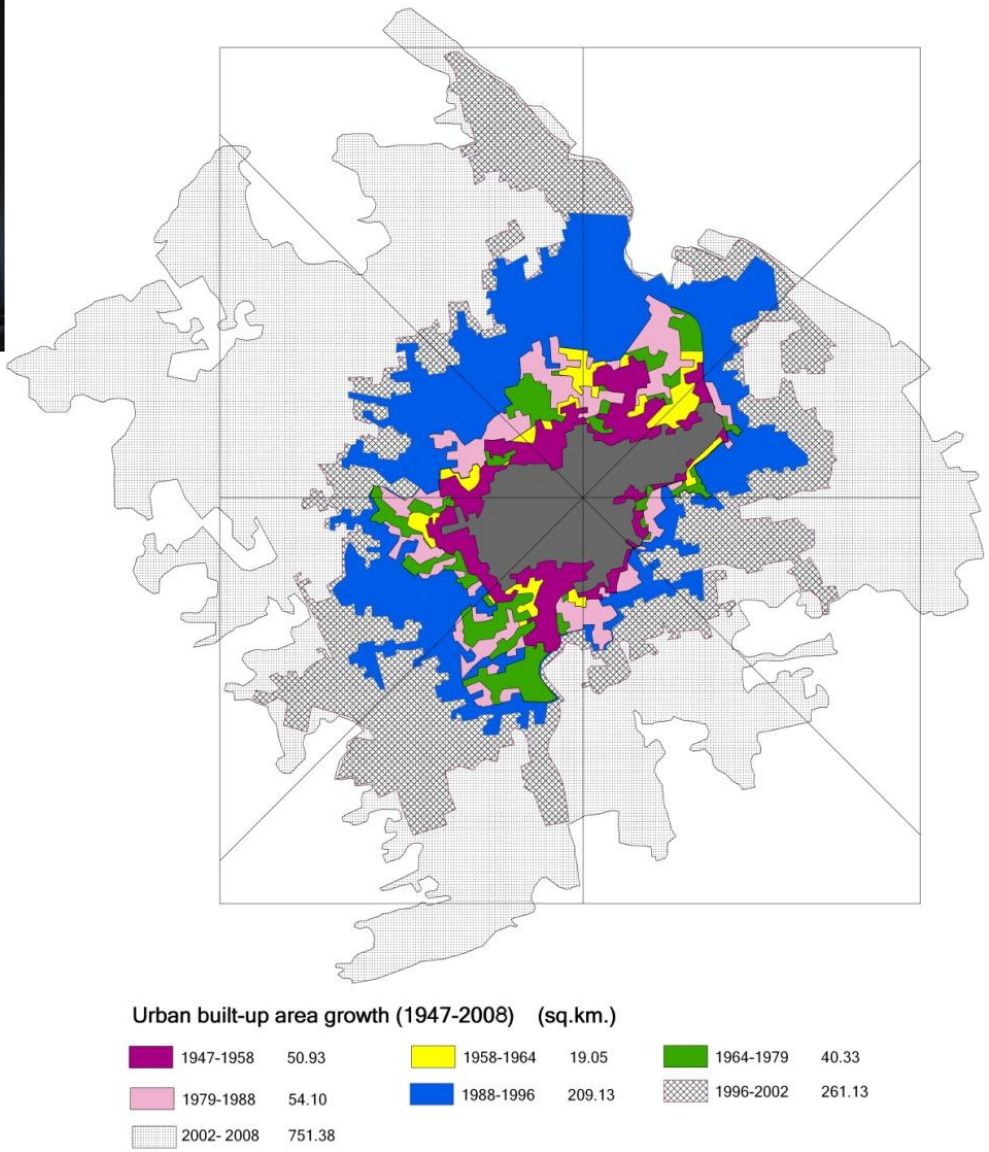
- **Urbanization and LCLUC**
  - Shanghai:
    - Urbanization , urban sprawl, & urban land transformation at district level
    - urban land use changes by different types
    - urban industrial land and its spatial determinants
  - Urumqi:
    - Urbanization, urban sprawl, degraded urban environment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

Shanghai

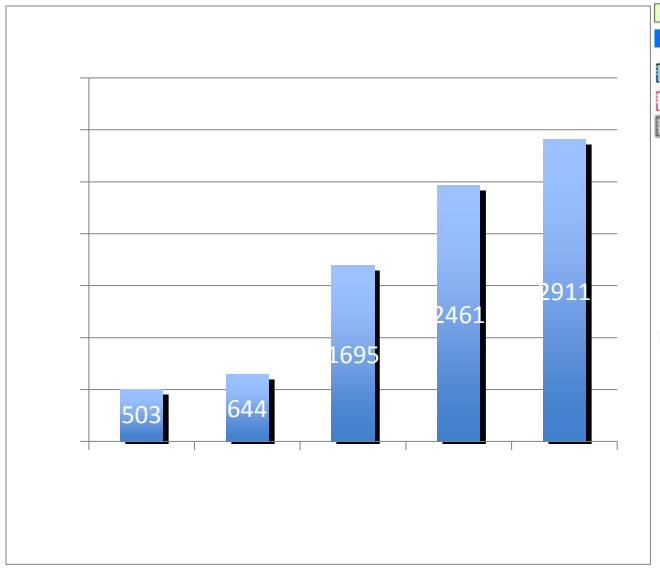
-General

- 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 km^2(2010)
  - Expanded almost 6 times
    - 530 (1986) => 2911 (2010)



Source: Yue et al, 2010; Fan et al, 2012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644
1695
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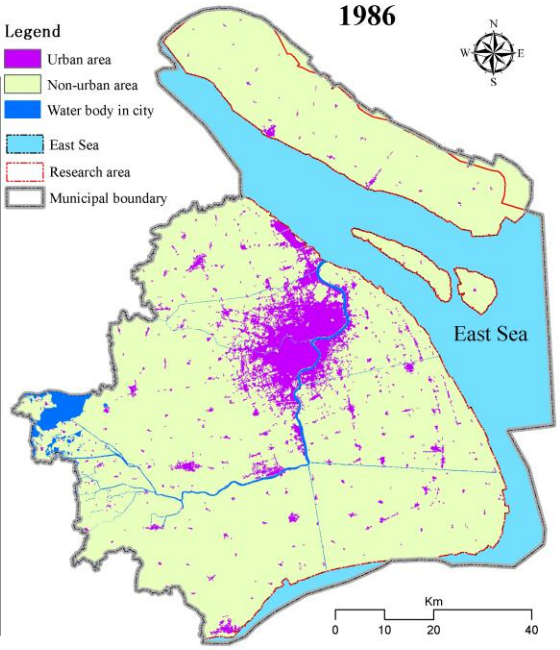
2911


1986
Legend
Urban area
Non-urban area
Water body in city
East Sea
Research area
Municipal boundary
East Sea
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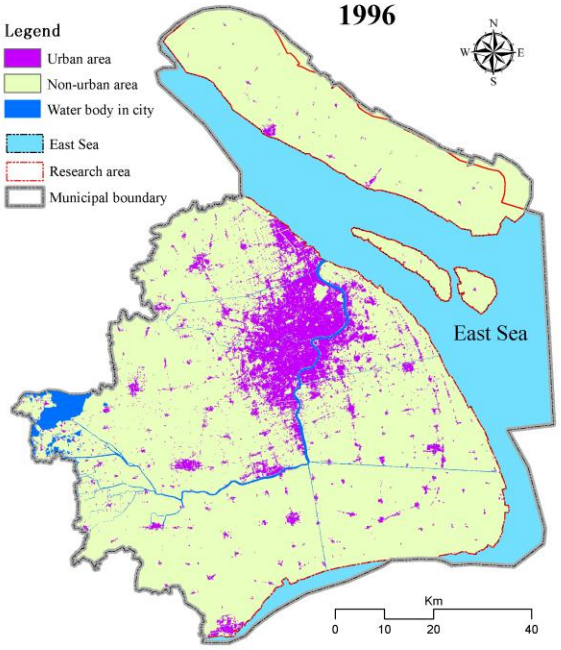
1996
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Urban area
Non-urban area
Water body in city
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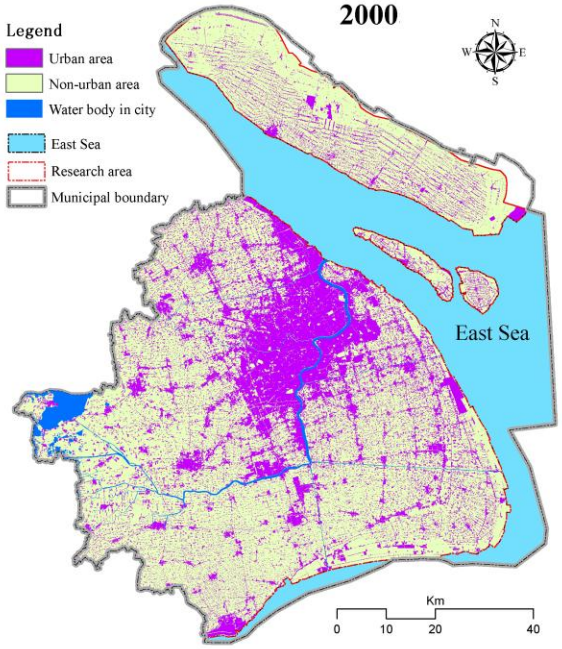
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Urban area
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Water body in city
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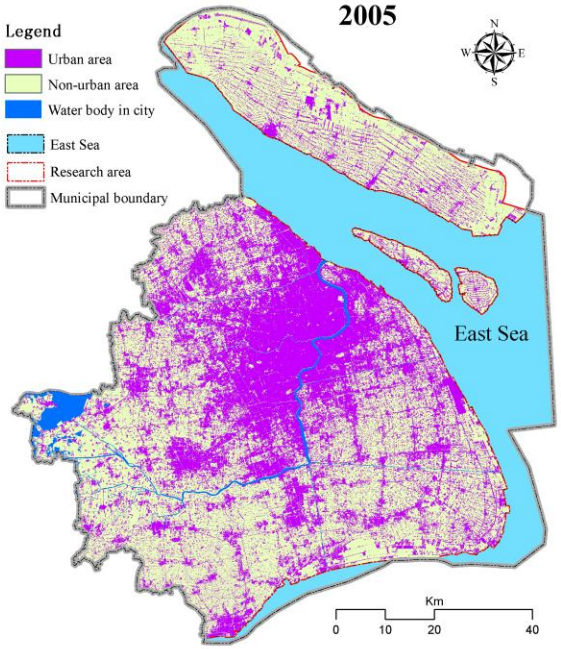
2005
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Urban area
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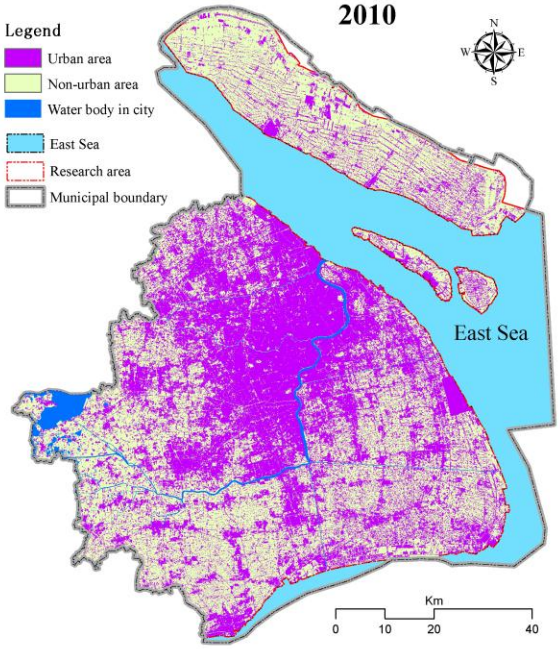
2010
Legend
Urban area
Non-urban area
Water body in city
East Sea
Research area
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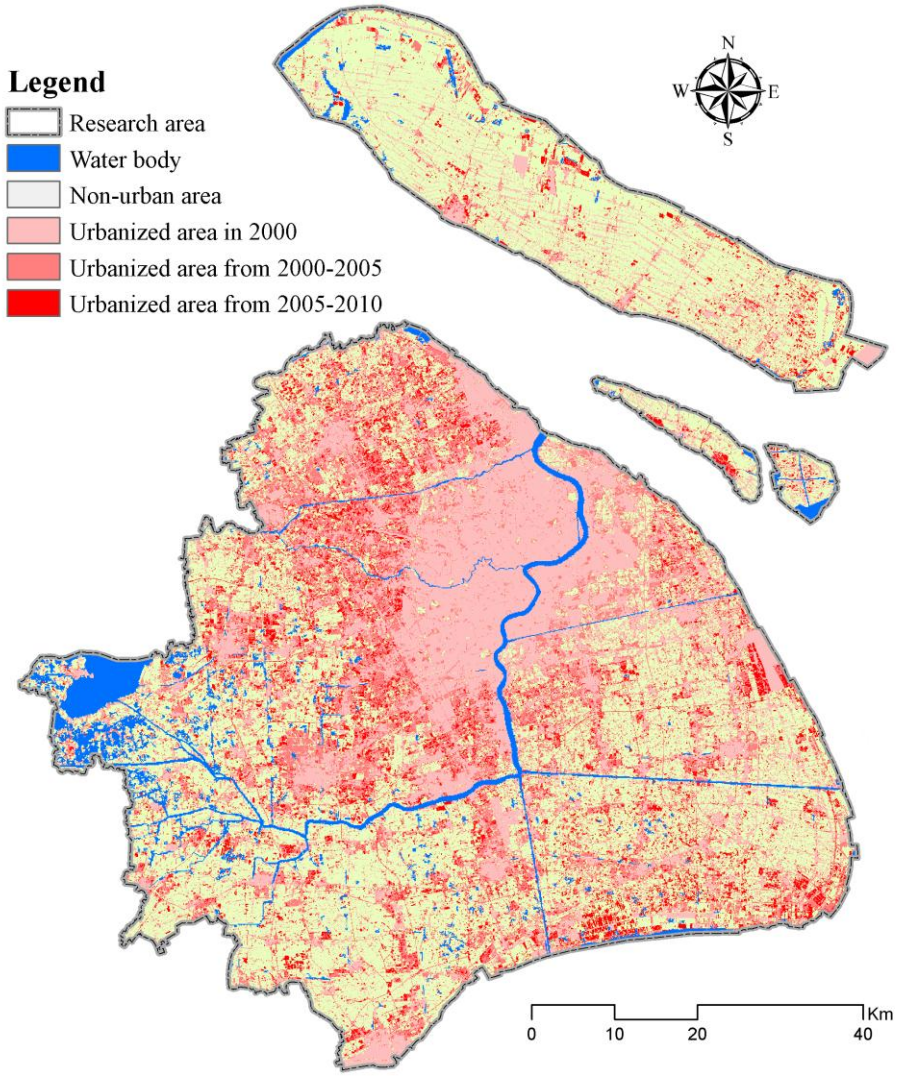
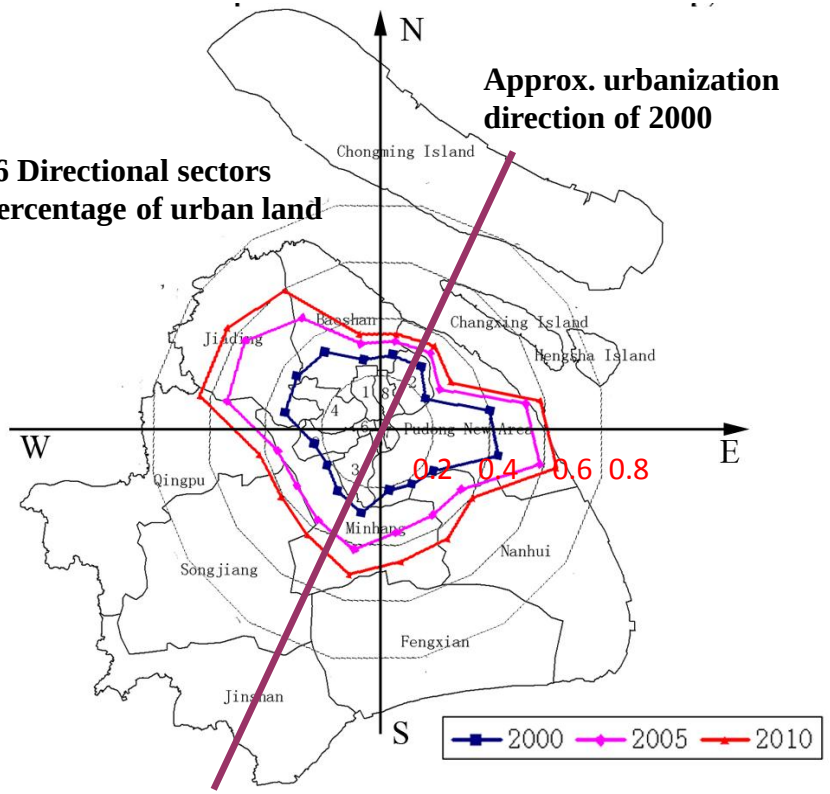
Urban expansion pattern (2000-2010)





- 1683 km^2 → 2883 km^2
- 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

		2005						
		Industrial	Transpor-tation	Urban	Green Land	Farm	Water	2000 Total
	Industrial	275.07	11.55	49.51	19.51	11.27	10.63	377.53
2000	Transpor-tation	26.26	119.05	33.28	3.01	19.67	3.76	205.05
	Urban	86.31	21.93	963.19	0.00	0.00	41.24	1112.67
	Green Land	15.80	6.10	32.35	26.85	36.24	7.30	124.64
	Farm	254.28	50.10	411.03	131.26	2811.03	0.00	3657.69
	Water	31.84	12.82	60.67	23.80	285.74	524.76	939.64
	2005 Total	689.55	221.55	1550.03	204.44	3163.94	587.70	6417.21

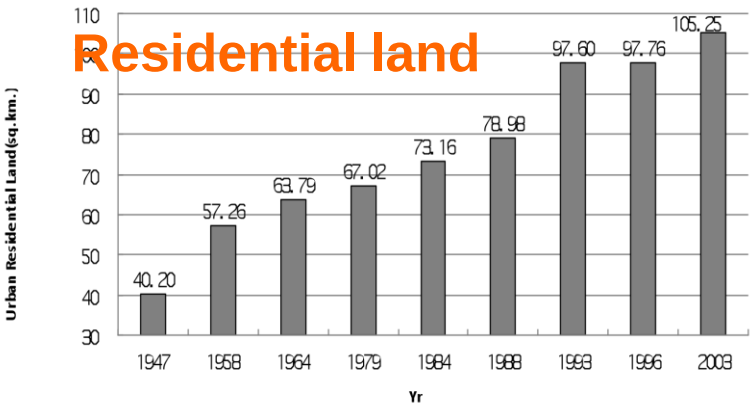
		2010						
		Industrial	Transpor-tation	Urban	Green Land	Farm	Water	2005 Total
	Industrial	416.86	0.53	195.92	10.92	55.12	10.21	689.55
2005	Transpor-tation	0.36	158.08	0.64	11.85	44.42	6.20	221.55
	Urban	144.92	45.71	1331.89	0.00	0.00	27.51	1550.03
	Green Land	0.00	0.00	0.00	204.44	0.00	0.00	204.44
	Farm	137.62	48.42	298.76	10.24	2557.76	111.14	3163.94
	Water	23.72	8.65	98.54	13.26	163.91	279.62	587.70
	2010 Total	723.48	261.40	1925.75	250.70	2821.21	434.67	6417.21

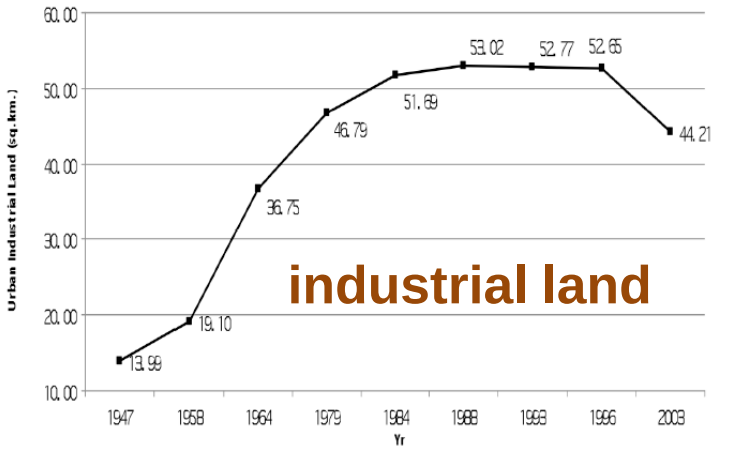
Shanghai –
Urban land use by types:

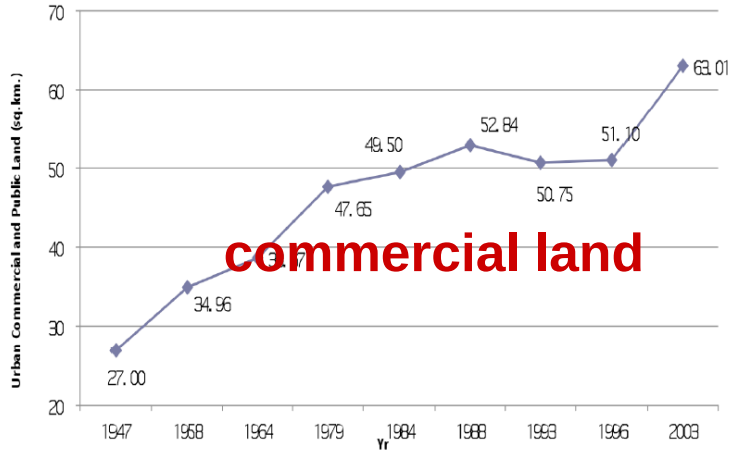
- *residential* - continuous growth
- *industrial* - declined 1993-2003
  relocation of factories
- *commercial* - climbing due to
  increased infrastructure investment,
  urban redevelopment

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



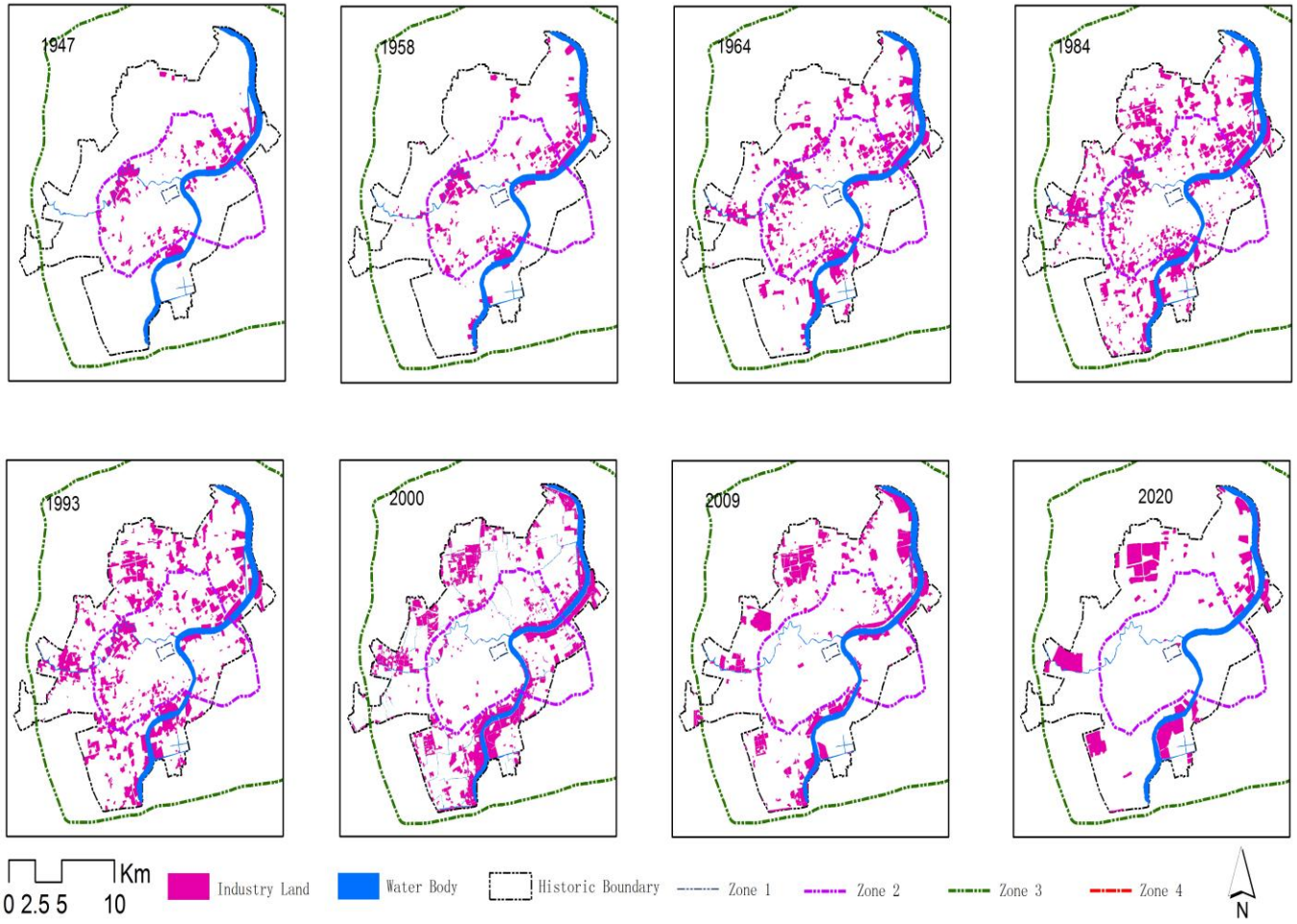




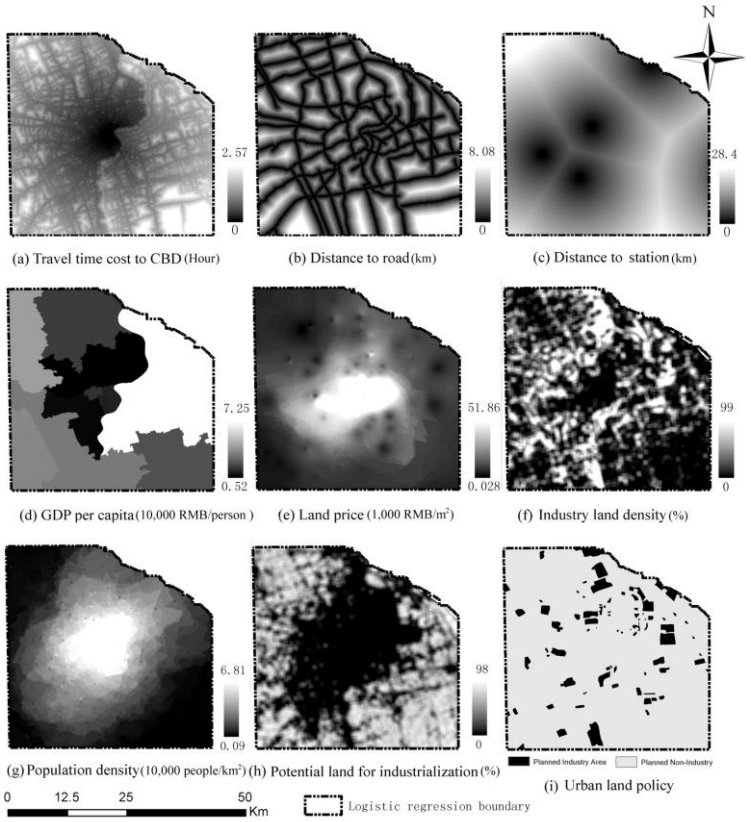
Shanghai –
Evolution of urban industrial land

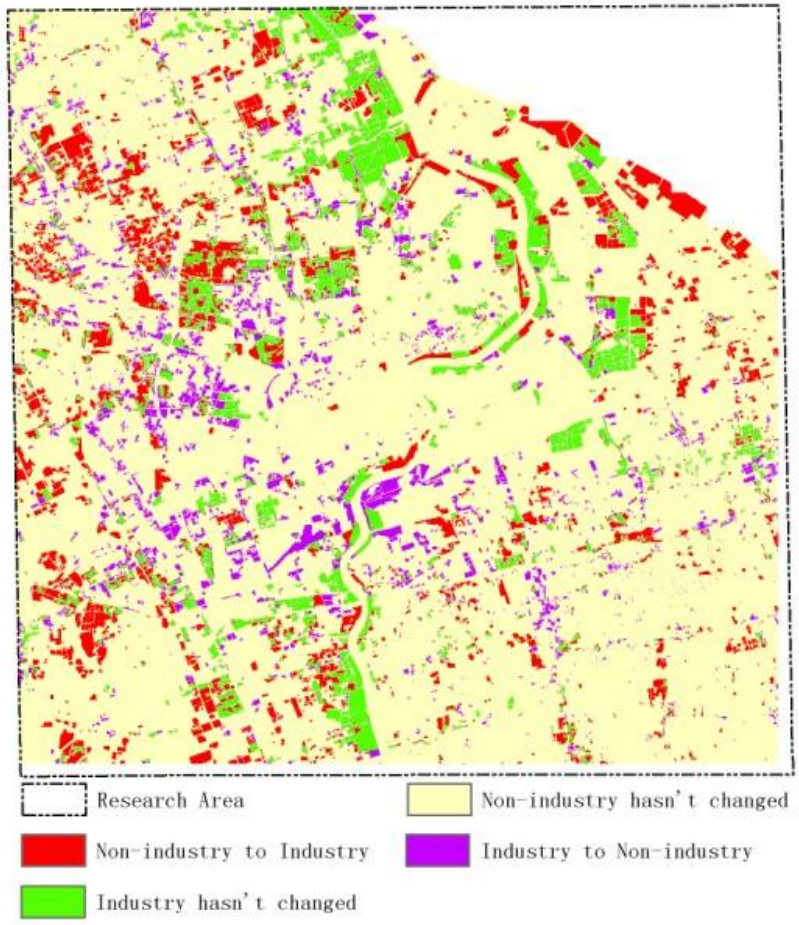
first increased rapidly 1947 - 1984, then started decreasing from 1993

a hybrid monocentric pattern => a specialized polycentric pattern



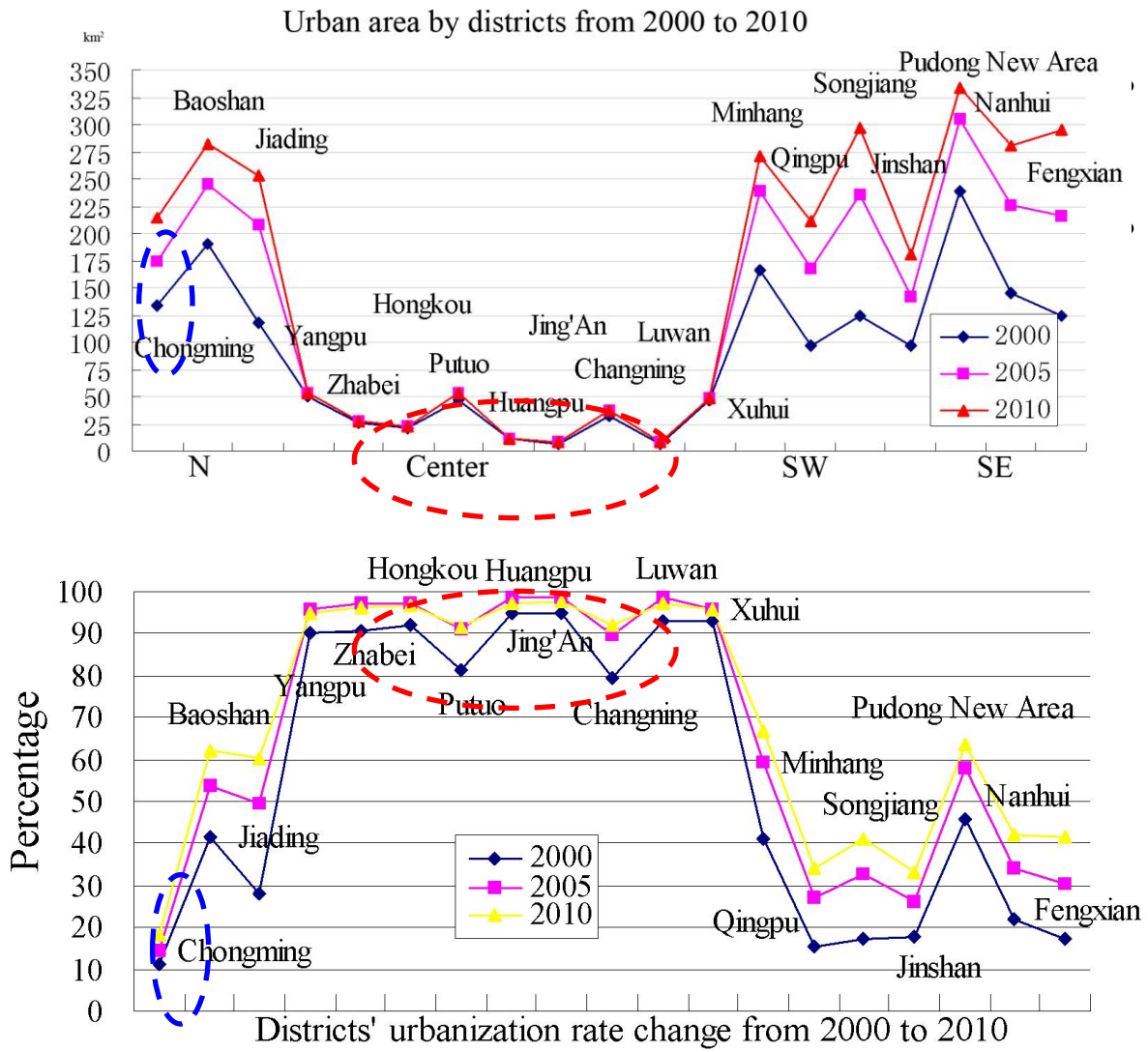
Shanghai – spatial determinants of urban industrial land conversion (2002-2009)





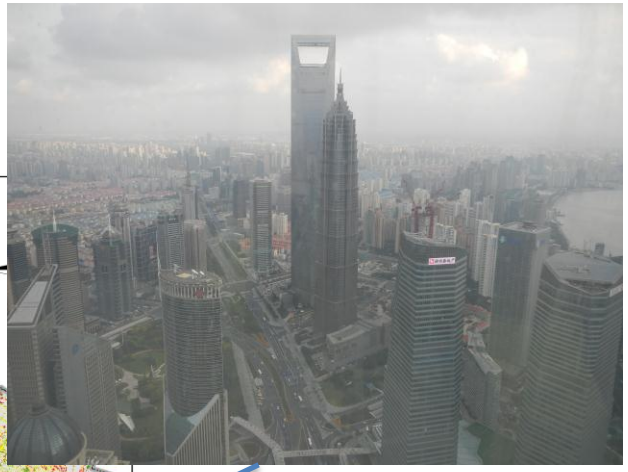
Major spatial determinants:
land price, existing industrial land, land policy

LCLUC at district level, 2000 – 2010

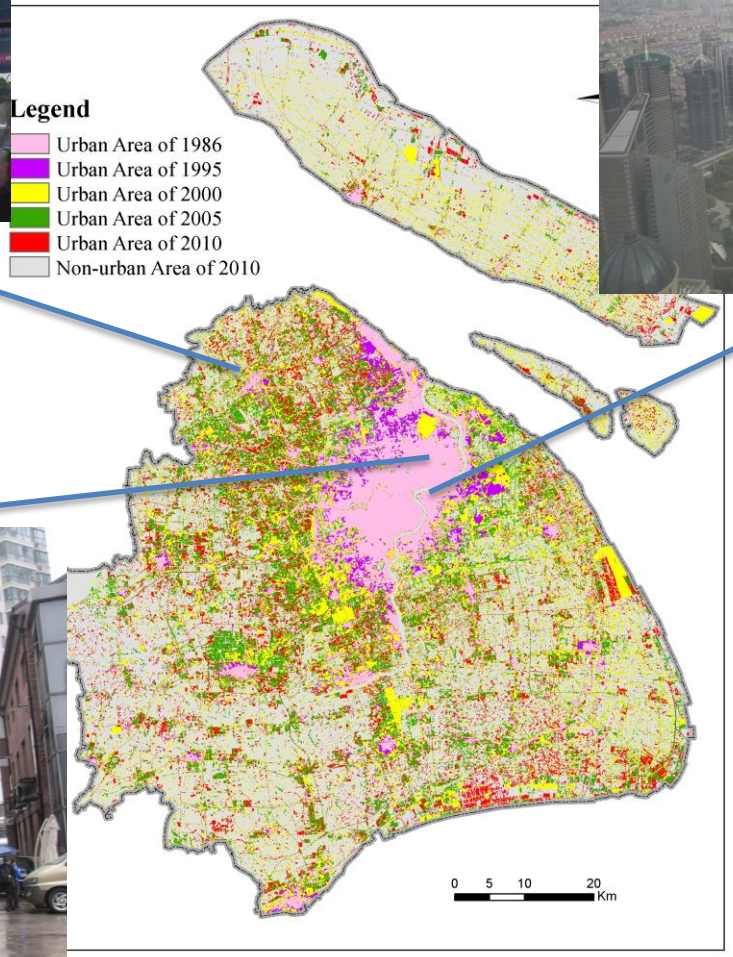


- Suburban districts
  - noticeable urbanizations
- City core districts (red oval)
  - relative intensive urbanizations were taking place (Putuo, Changning)
  - city planning: urban redevelopment, industry reallocation
- Chongming (blue oval)
  - high absolute urban land
  - relative low urbanized rate
  - Ecological land (2005)

Suburban low-density industrial zone



Rising new CBD in Lujiazui, Pudong



Redevelopment at old urban district

Case 2: Urumqi –urbanization and urban sprawl

Urumqi, Capital of Xinjiang Uyghur Autonomous Region

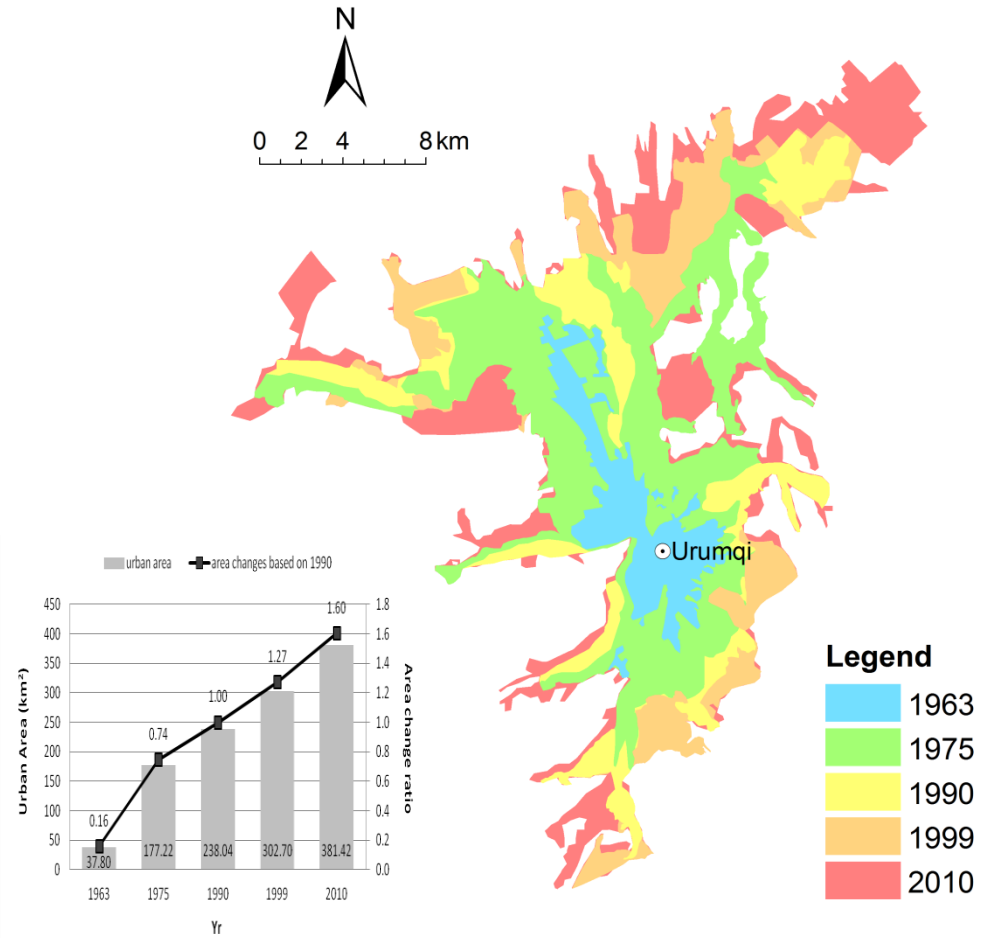
- important trading center for centuries
- military base
- westward migration - factor in industrialization

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

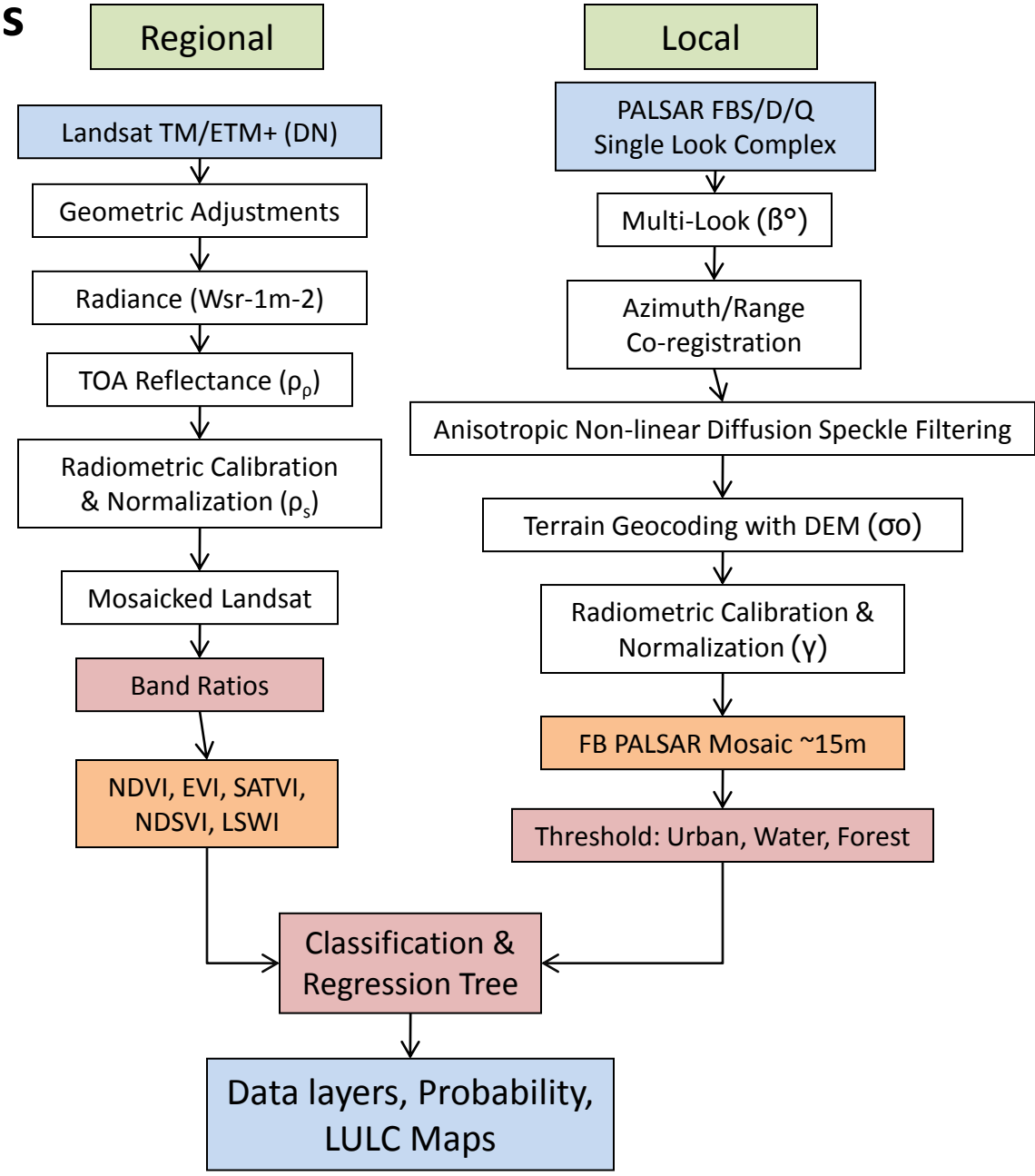
•used GLS / Landsat TM time series to map LULC in 1975, 2000, and 2010

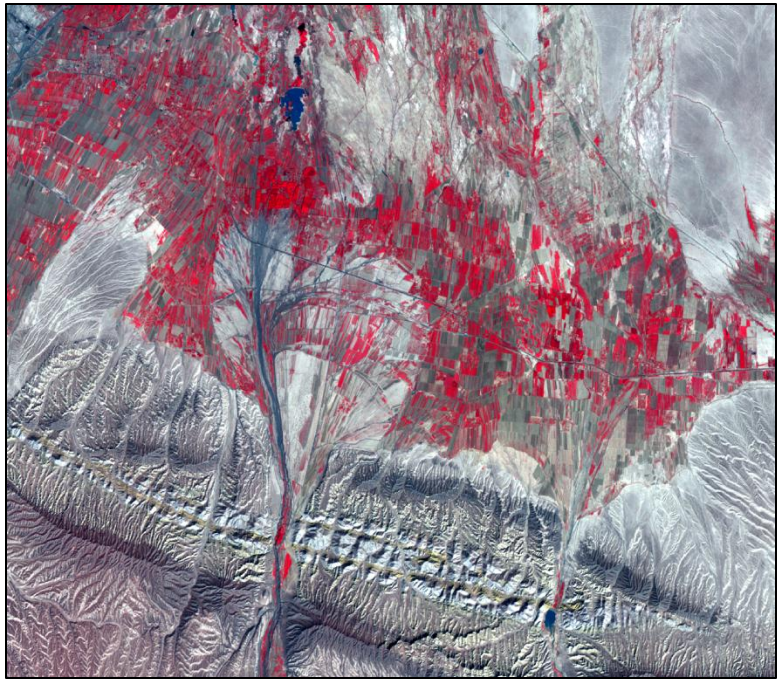
•integrate Landsat TM & ALOS PALSAR to map urban and assess LCLUC to 2010

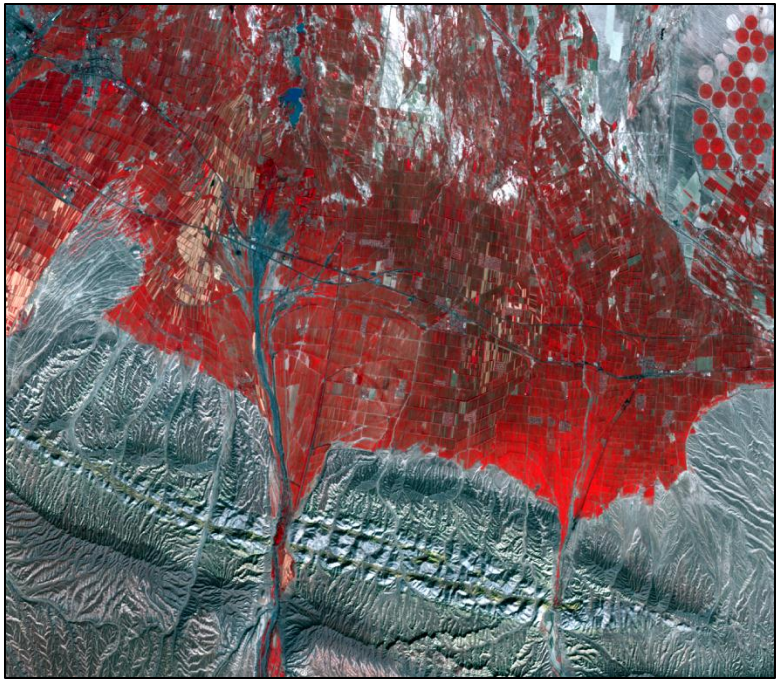
• Preprocessing streams for data =>

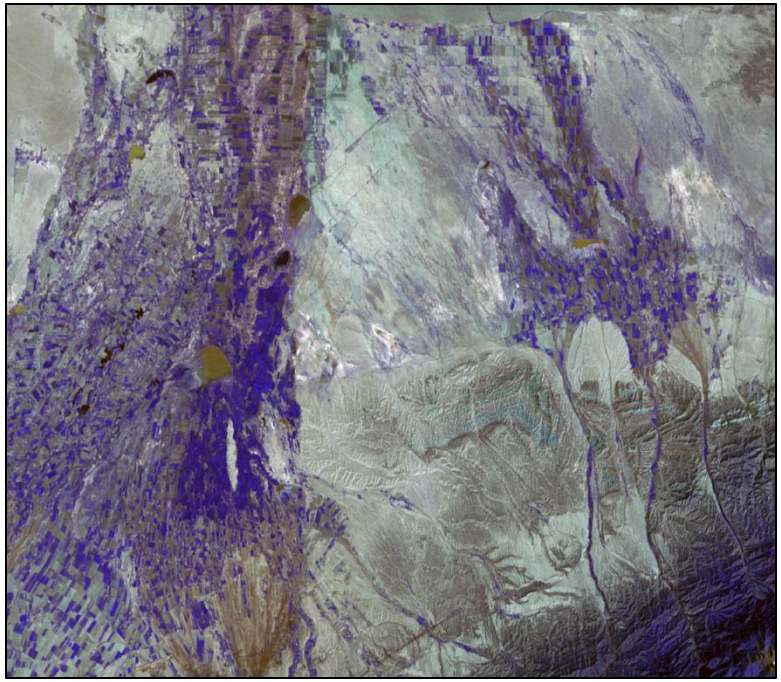
• Approach used a CART

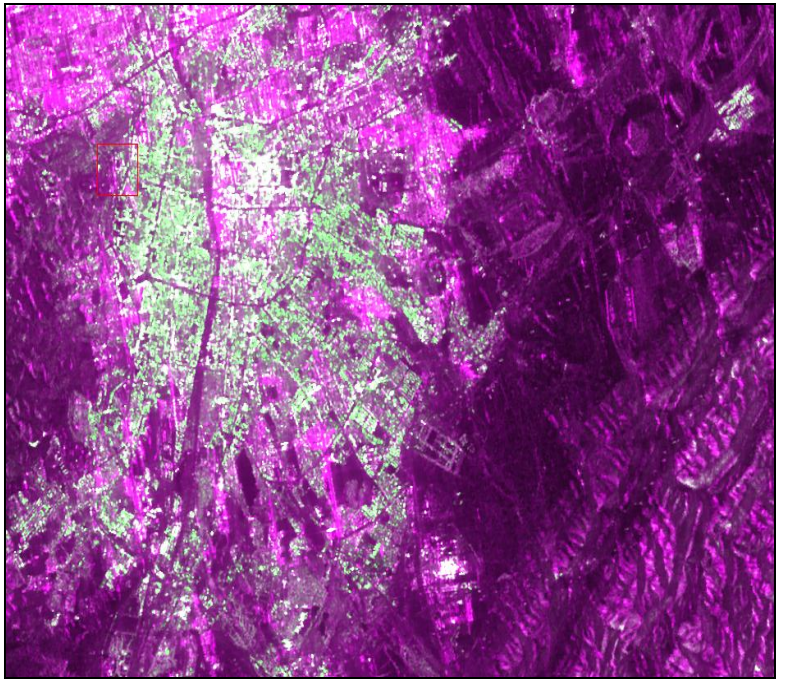
• Post processing applied operational thresholding of Landsat, PALSAR, and Aster DEM indices to adjust products

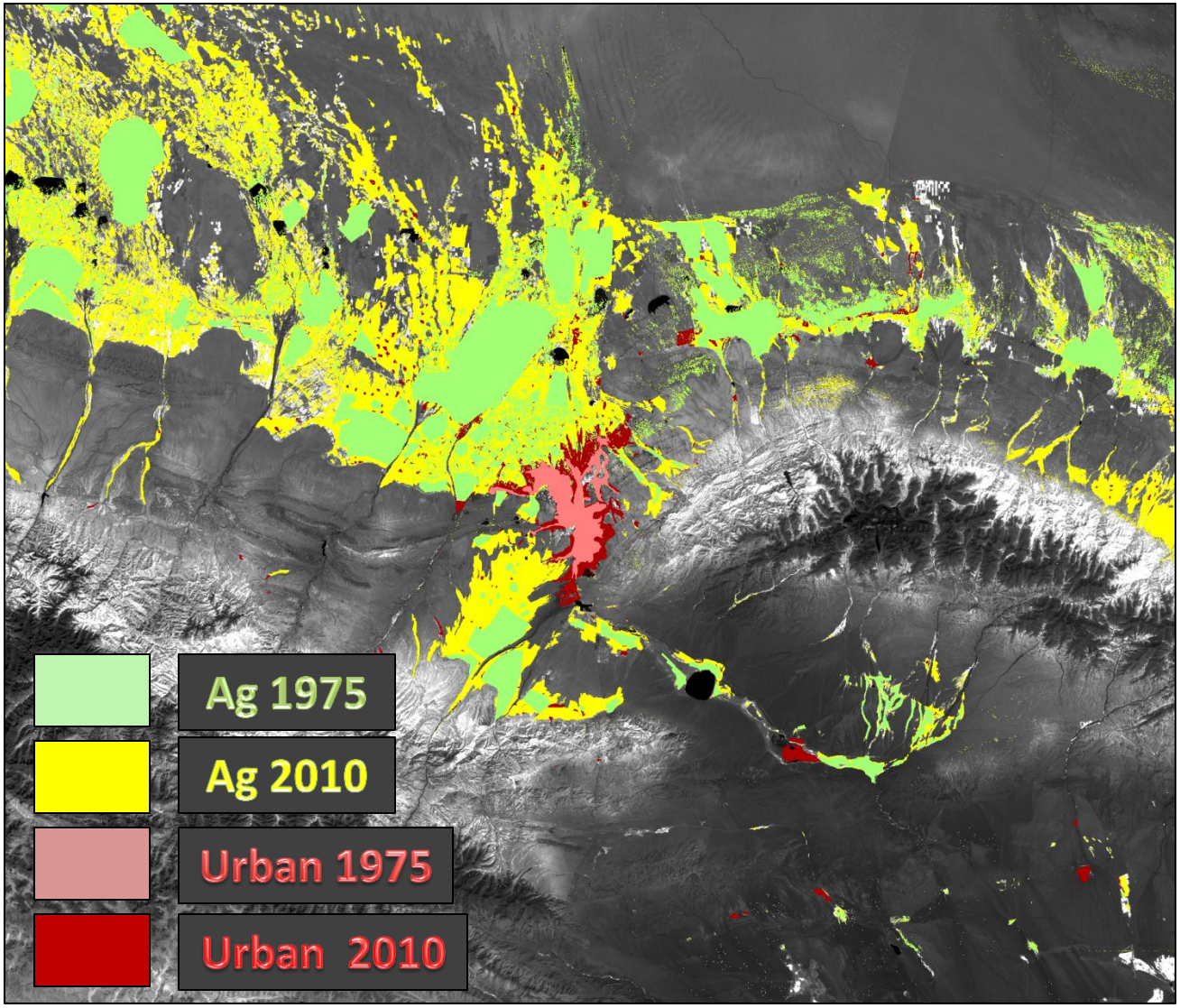


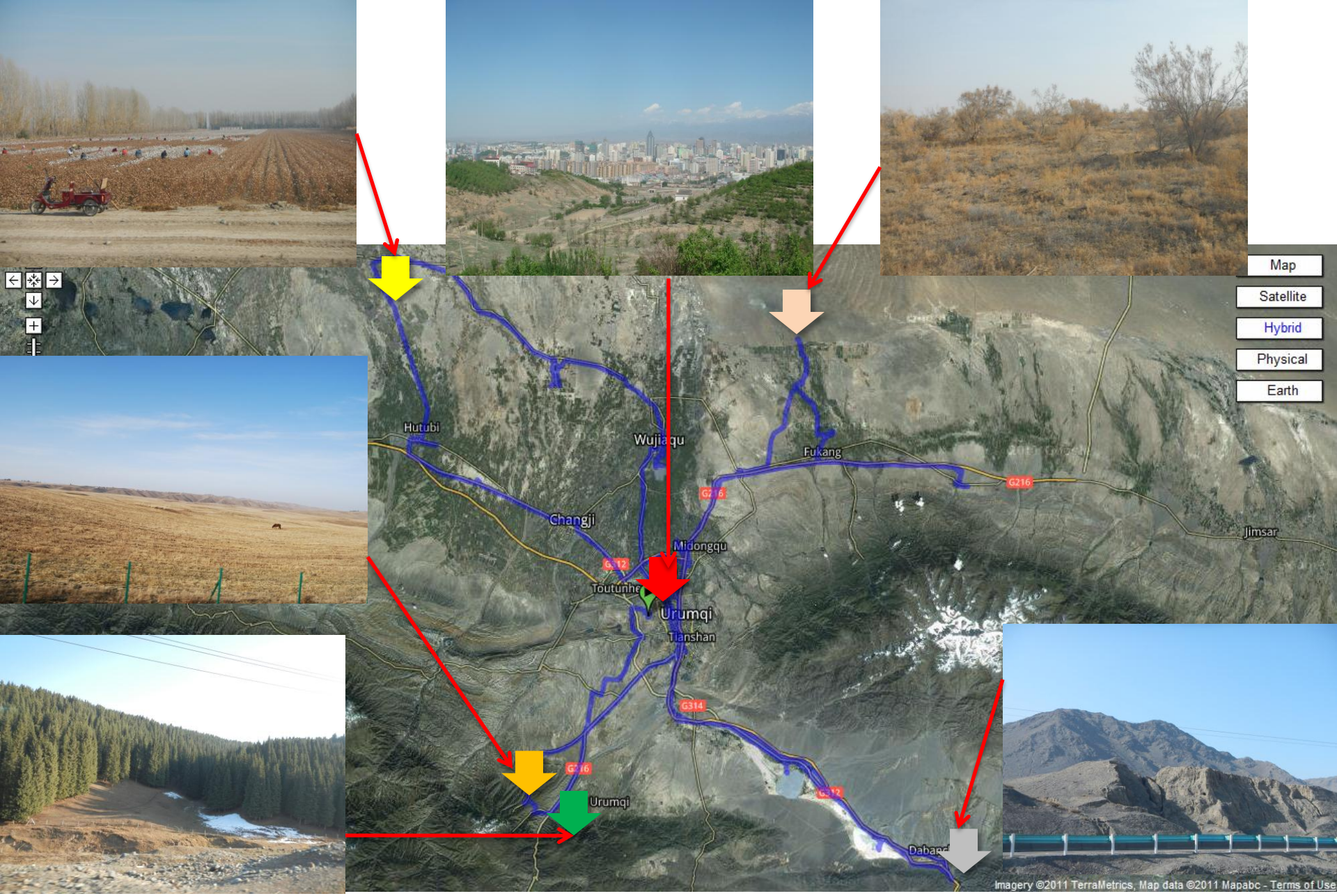









Ag 1975
Ag 2010
Urban 1975
Urban 2010


Map
Satellite
Hybrid
Physical
Earth
Hutubi
Wujiaqu
Fukang
Changji
Midongqu
Toutunhe
Urumqi
Tianshan
Urumqi
Jimsar
G216
G314
Imagery ©2011 TerraMetrics, Map data ©2011 Mapabc - Terms of Use
urban
cropland
shrubland
grassland
forest
barren

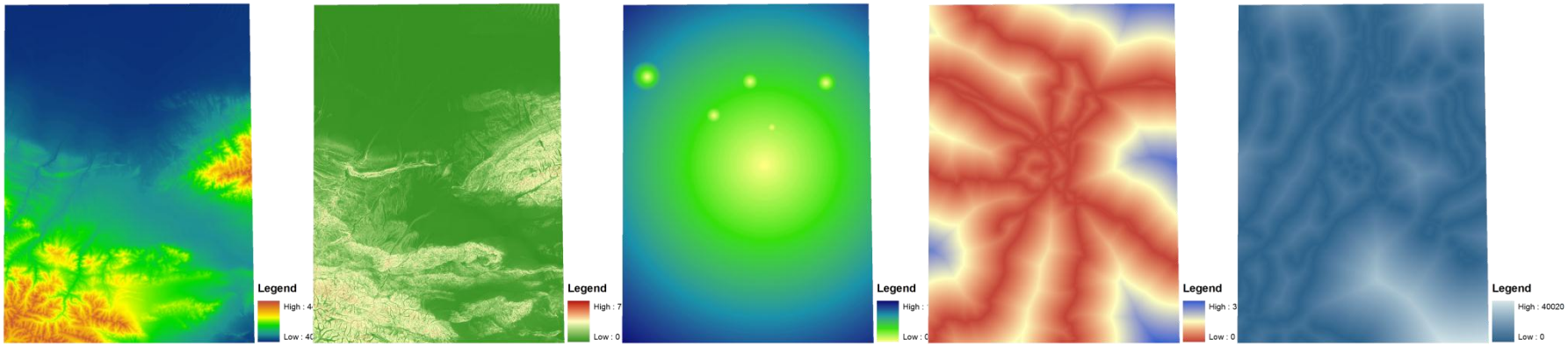
Objective 2

- **Simulation of future LCLUC and regional climate changes, impact of climate change, and adaption 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



DEM *Slope* *Distance to cites* *Distance to roads* *Distance to water*

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

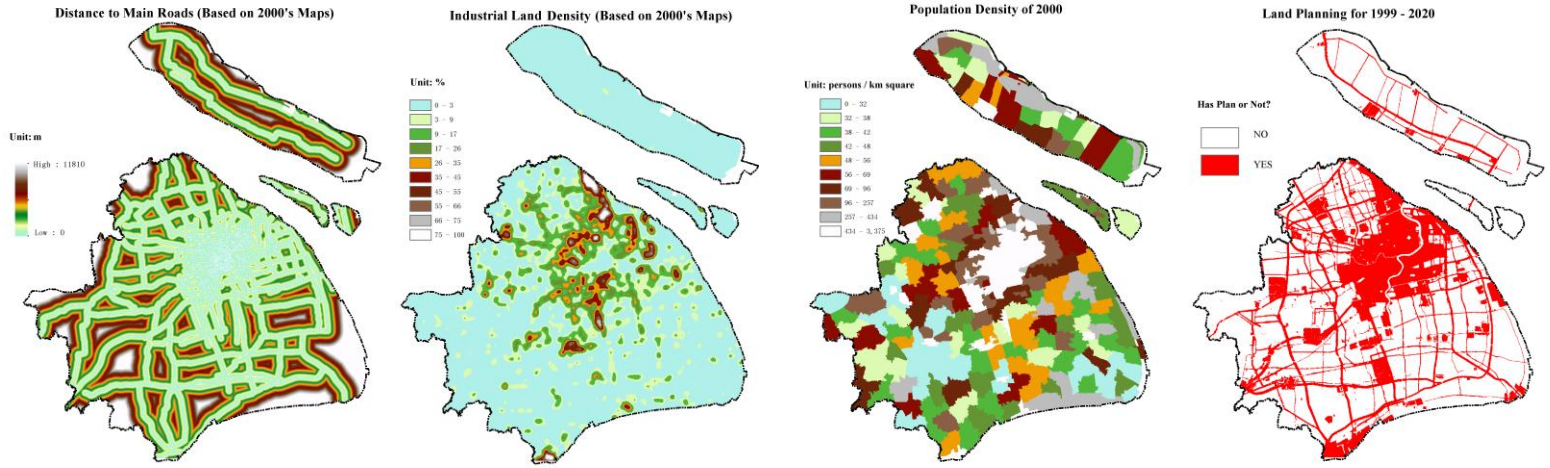
Where:
Pi is the probability of a grid cell for the occurrence of the considered land use type on location i;
X's are the location factors.

var.	intercept	dem	slope	city	road	water
estimates	3.880e+00 *	-1.211e-03 *	-1.518e-01 *	-5.710e-05 *	-8.680e-05 *	5.385e-05 *
D^2	0.4678					

Signif. codes: 0 '*' 0.001 D^2 = 1-(residual deviance/null deviance)

Clue-s Simulations (2000-2020)

--Contributing factors for Urban Land Presence



--Three Scenarios

Scenario Name	Description
Base	Urbanization occurs with a linear growth rate with no specific protection of urban green land
Unrestricted	Urbanization occurs with a decelerating growth rate (nonlinear) and with no specific protection of urban green land
Restricted	Urbanization occurs with a decelerating growth rate (nonlinear) and with specific protection of urban green land

b) Clue-s Simulations (2000-2020)

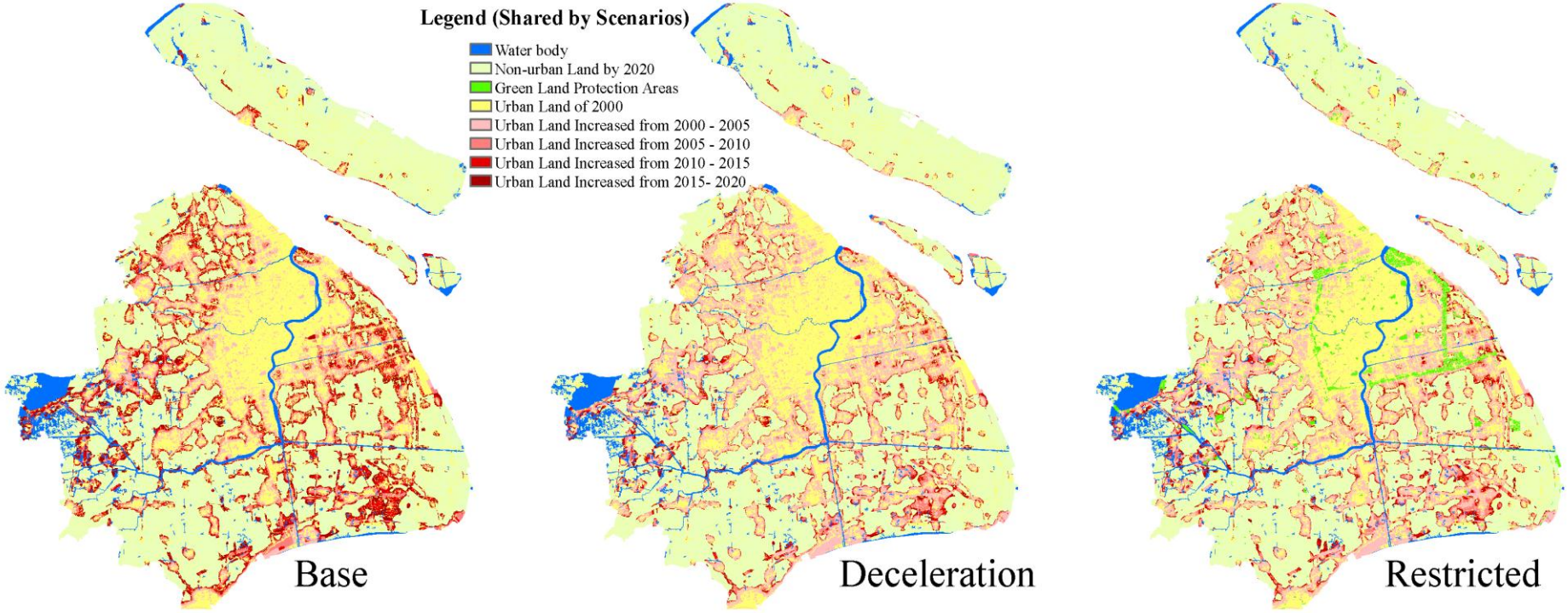
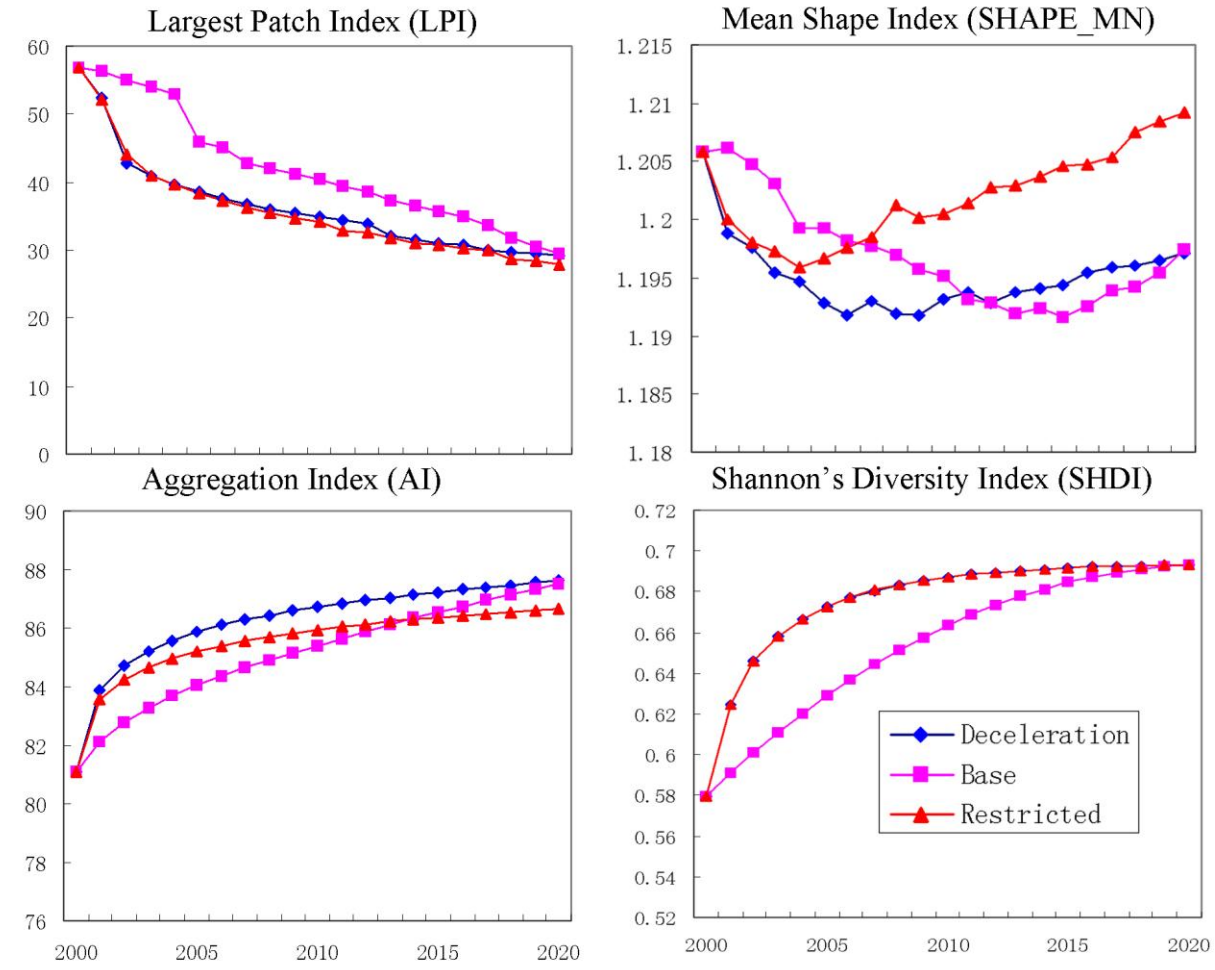


Figure 4: LUCC Simulations for 3 Scenarios

- 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



◆The deceleration and restricted scenarios: the same patterns for land metrics LPI and SHDI

◆The restricted scenario-the most complex landscape

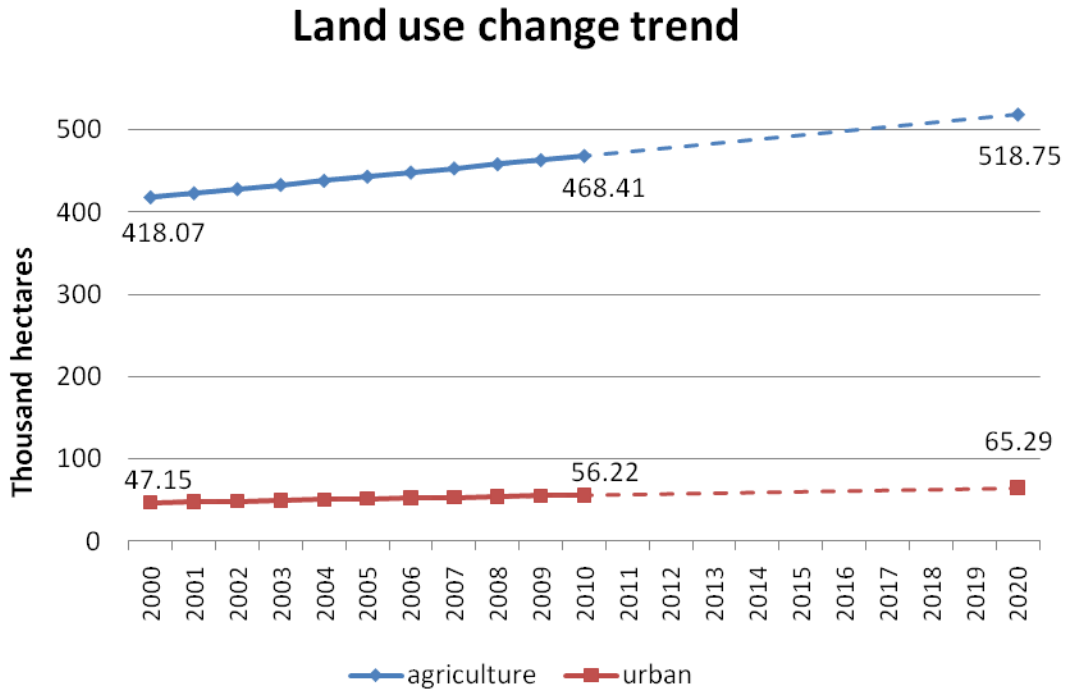
◆the deceleration scenario-the most aggregated landscape.

◆SHAPE_MN decreases in all scenarios, but increases for the restricted scenario after 2004.

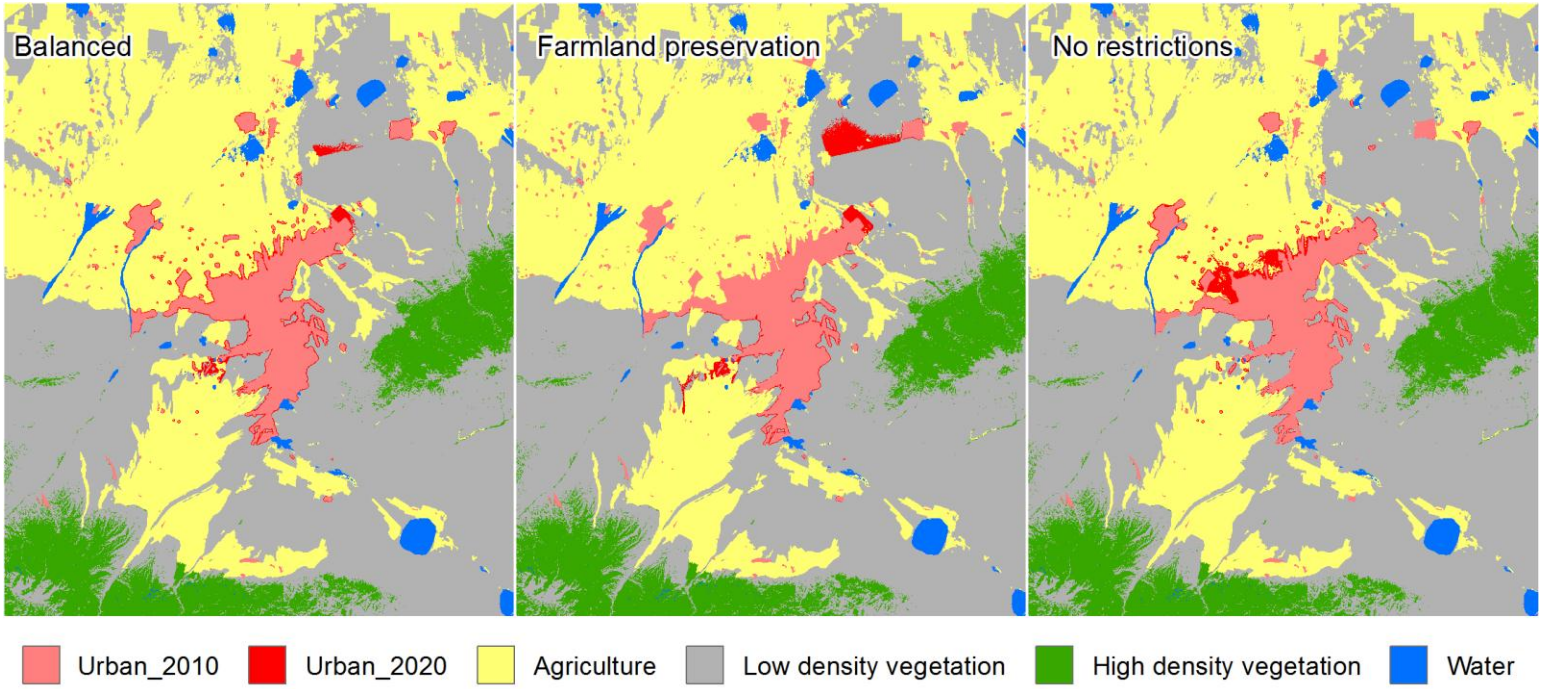
Figure 5: Selected Landscape Metrics Reponses of Scenarios

Urumqi Land use change simulation

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



Dyna-CLUE: simulation results



From\To	Balanced	Farmland preservation	No restrictions
U	56220.8	56220.8	56220.8
A	**4078.44**	**1118.88**	**7077.6**
LV	**5335.56**	**8232.48**	**1845.0**
HV	0.00	0.00	0.00
W	0.00	0.00	0.00

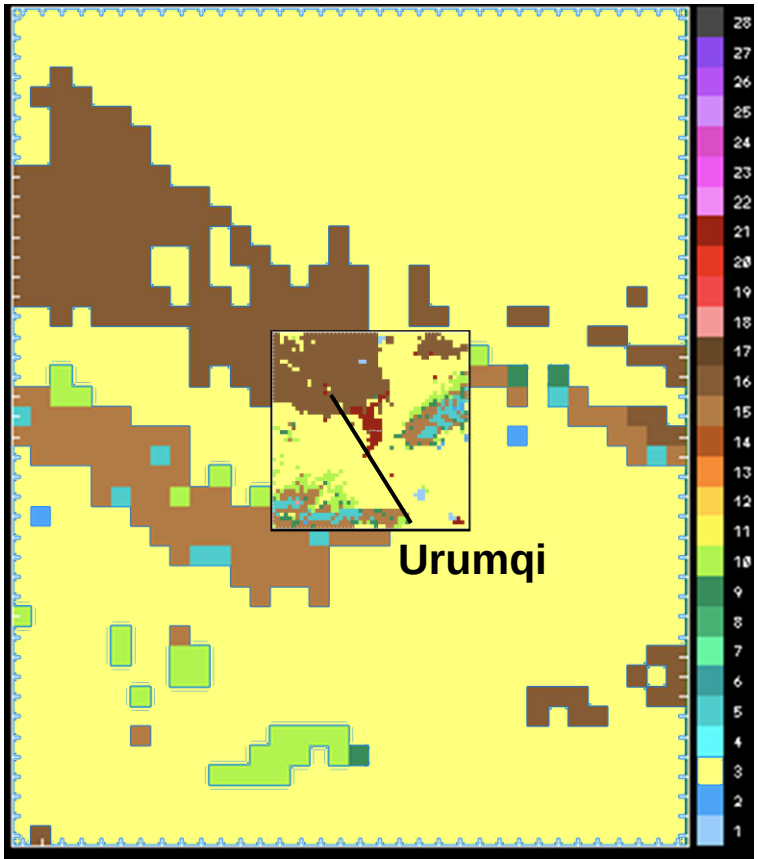
2b Regional climate simulation under IPCC scenarios

- 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

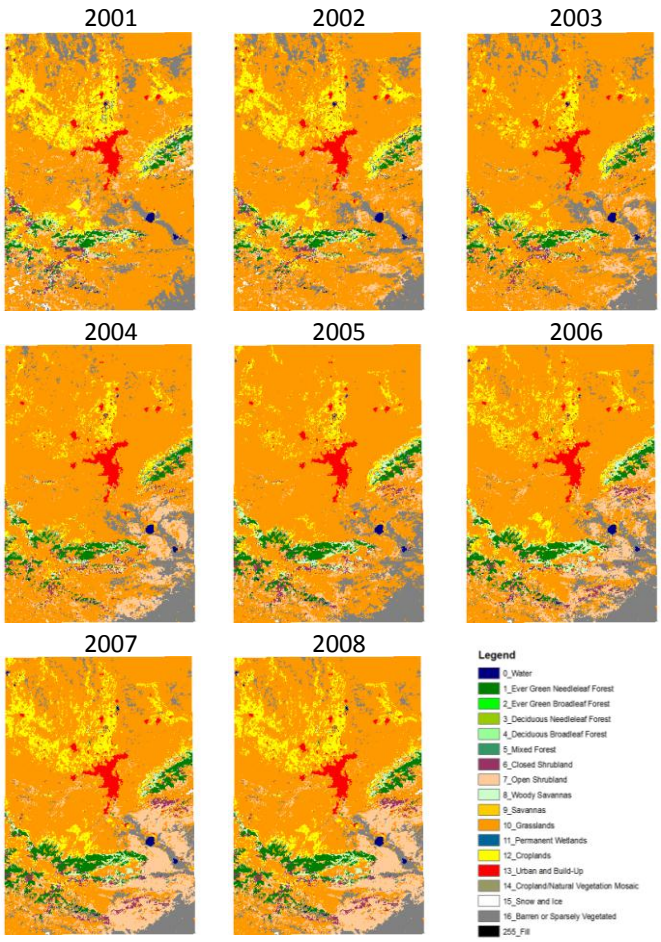


Preliminary results

- 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



Trajectory analysis

Categorical uncertainty

	6	7	8	10	12	16
6						
7	+					
8	-	-				
10	+	+++	+			
12	-	-	-	++		
16	-	++	-	+++	-	

+++very high, ++high, +moderate, -low

MODIS land cover codes:
6-Closed shrublands
7-Open shrublands,
8-Woody savannas
10-Grasslands,
12-Croplands
16-Barren or sparsely vegetated

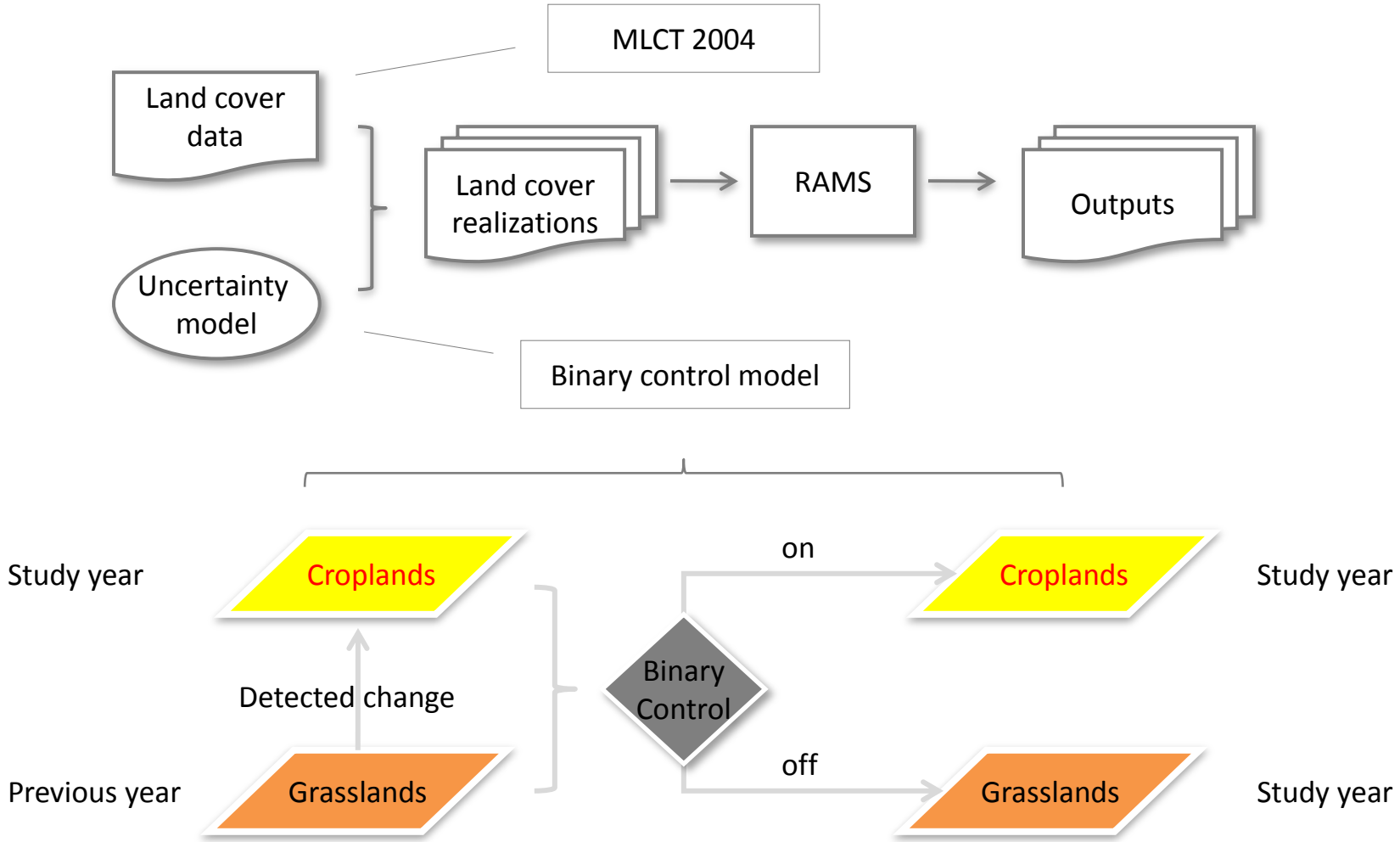
Uncertainty propagation through RAMS

•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.

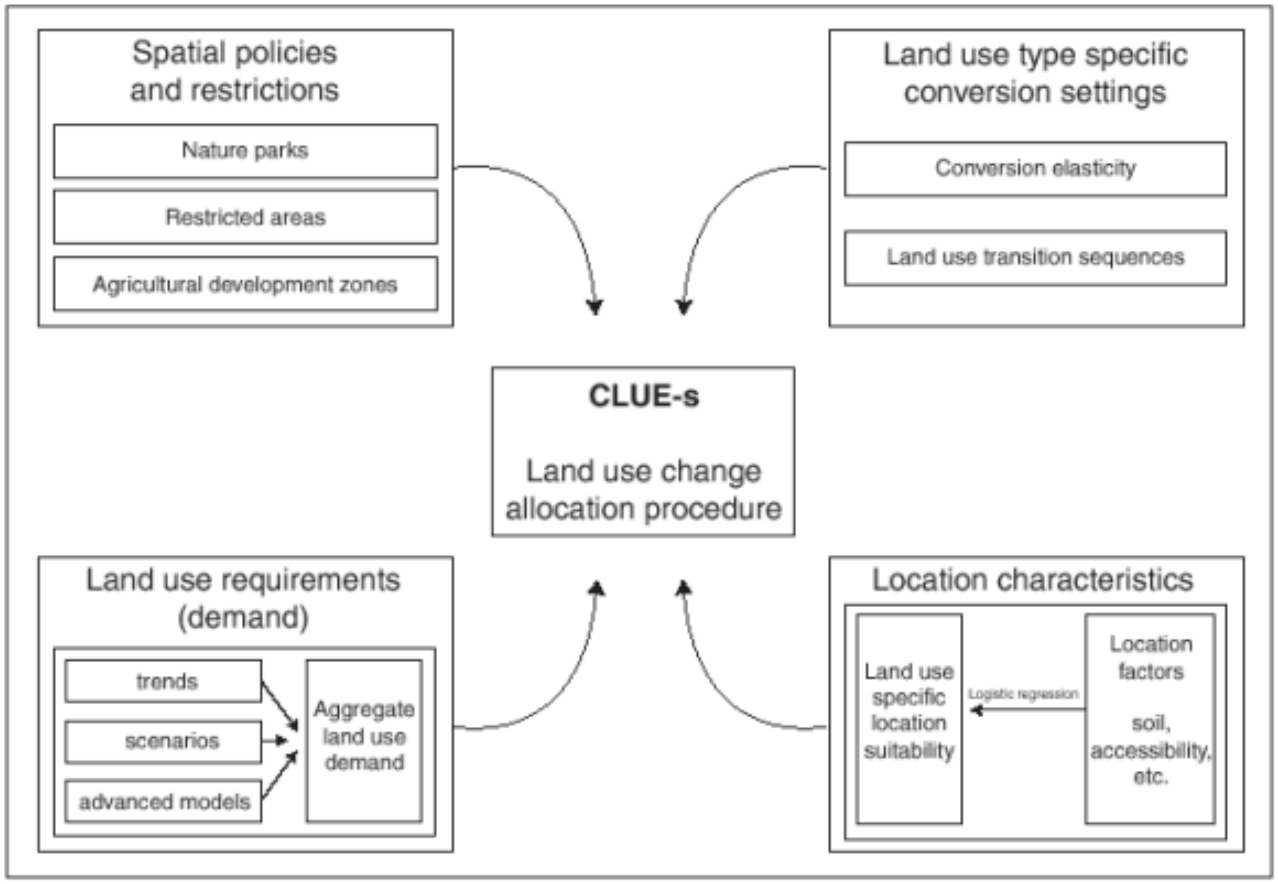
•the land cover realizations => RAMS

•analyze the RAMS results to study the potential impact of uncertainty from MLCT products.



Urumqi Land use change simulation

- dyna-CLUE model



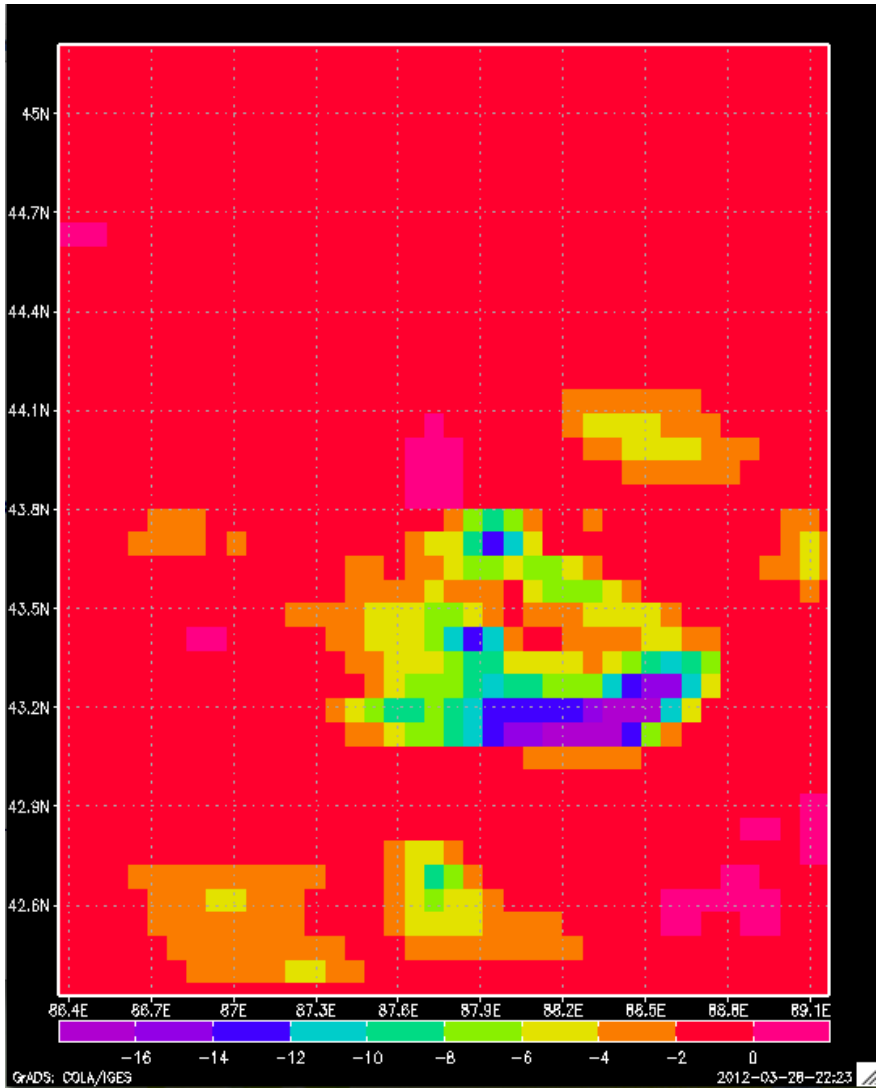
Source: Verburg et al, 2002.

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.**

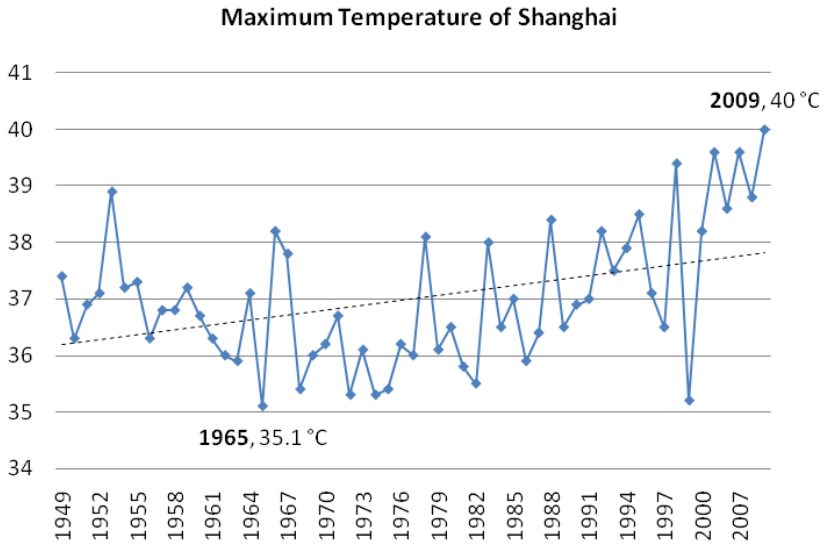
64 maps of Urumqi land cover have been imported into RAMS and are being simulated at a 2km grid spacing (expected to be complete in July)

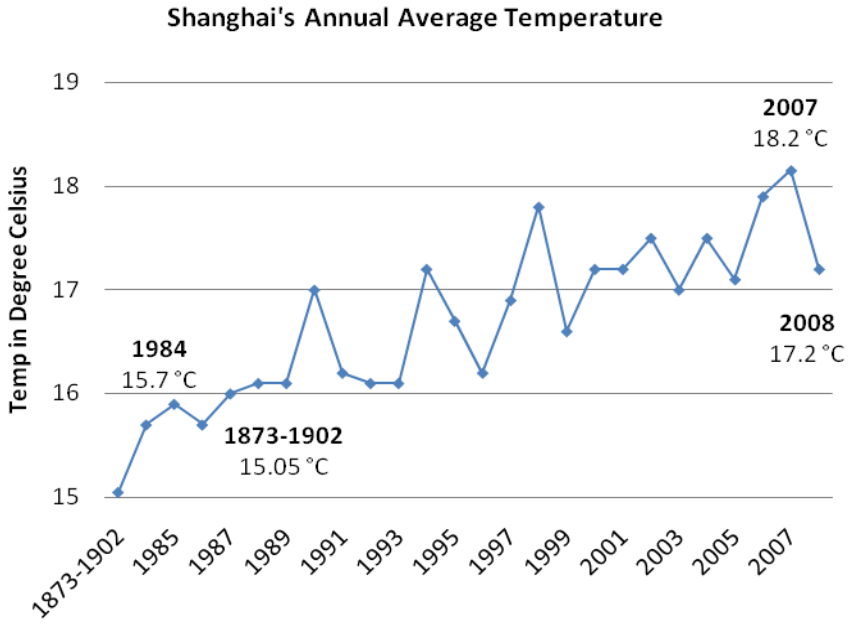


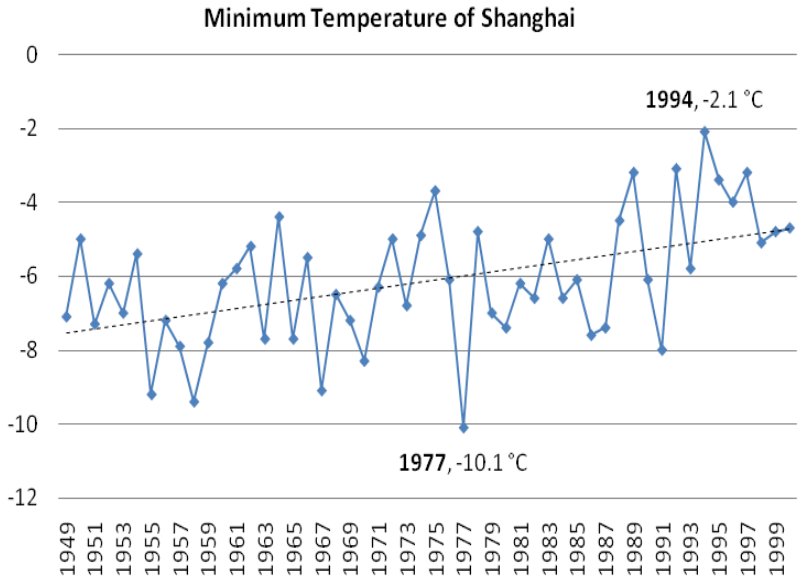
2c Impact of climate change on cities & 2d Adaptation and mitigation strategies

-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





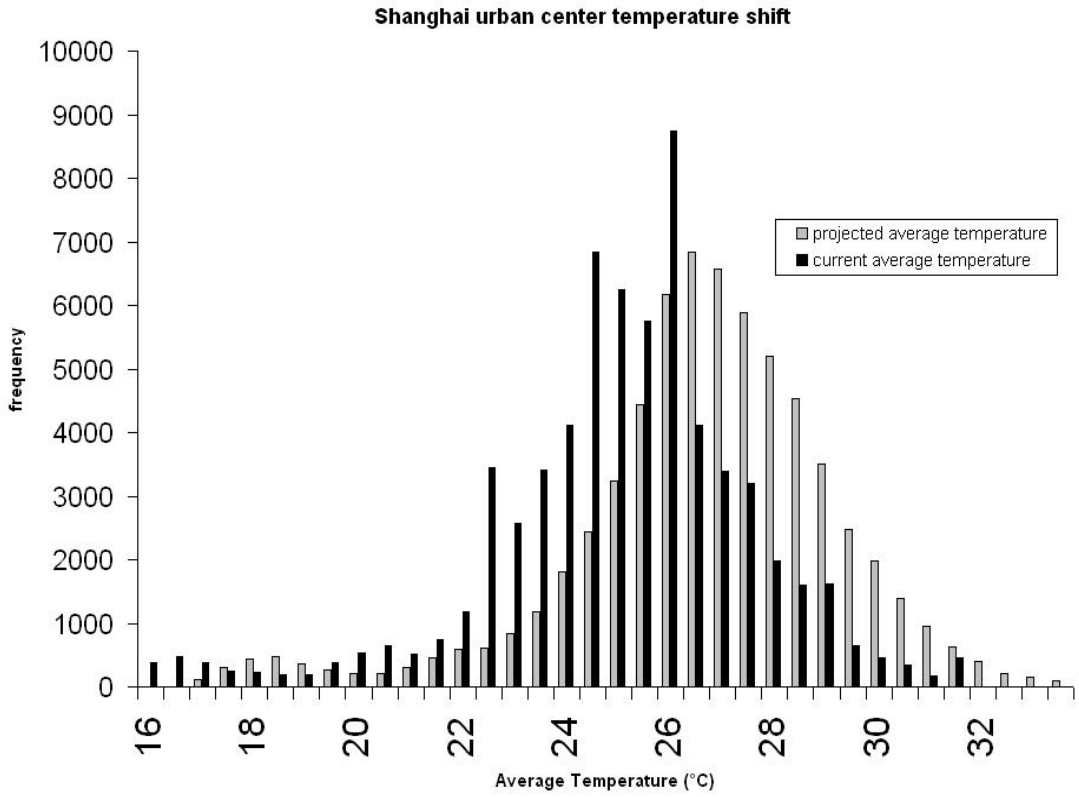


Future climate - Shanghai

- Statistical downscaling method

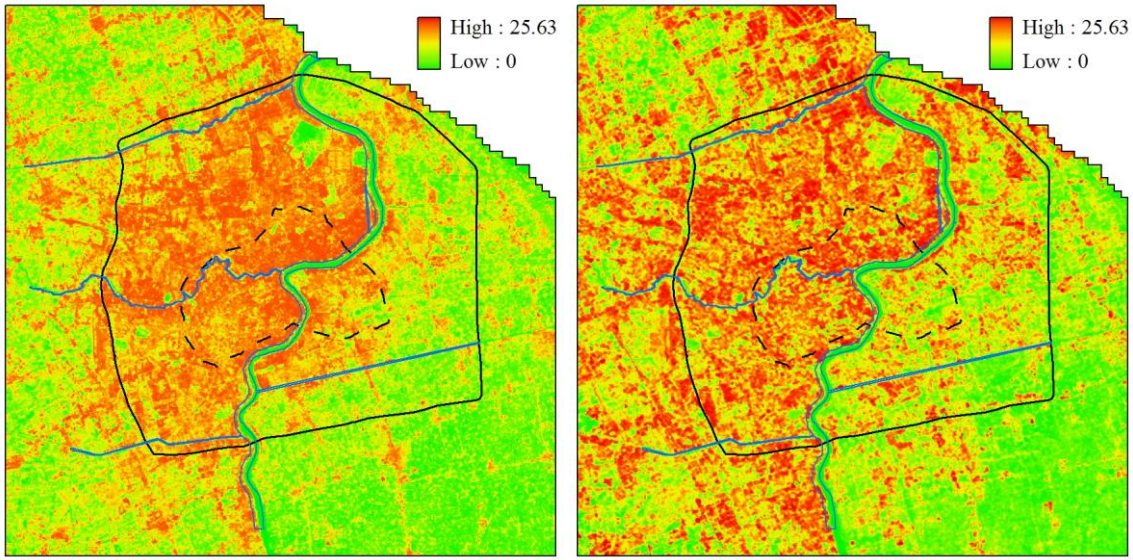
- an obvious shift in mean temperature in urban center
  - a 1.2˚ C shift in average July temperatures
  - consistent with a mid-century A1B trend

- 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



Shanghai's urban thermal environment (unit: ℃) (L: 2000, R: 2008)

- 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

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
  - Fan P and Qi J. 2010. Assessing the sustainability of major cities in China. *Sustainability Science Journal* 5(1): 51-68.
  - Fan P, Yue W, Huang H, Messina J, Qi J, Verburg P, Moore N, Ge J. (in revision). Forward to a post-industrial city? The evolution of the urban industrial land in Shanghai. *Landscape and Urban Planning*.
  - Yue W, Fan P, Qi J, Liu Y. (in revision) Spatial differentiation and the coupled development of economy and environment in Shanghai. *Stochastic Environmental Research and Risk Assessment.*
  - Li X, Messina J, Fan P, Moore N, Shortridge A. (in submission) Propagation of Land Cover Uncertainty in Climate Simulations.
  - Yue W, Liu Y, Fan P, Xu J. (in submission) Quantifying the impact of human activities on spatial pattern of the urban thermal environment: a case study of Shanghai.
- 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

Thank you!

Urumqi
Fieldtrip in May 2010

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