West meets East: Monitoring and modeling urbanization in China

Land Cover-Land Use Change Program Science Team Meeting
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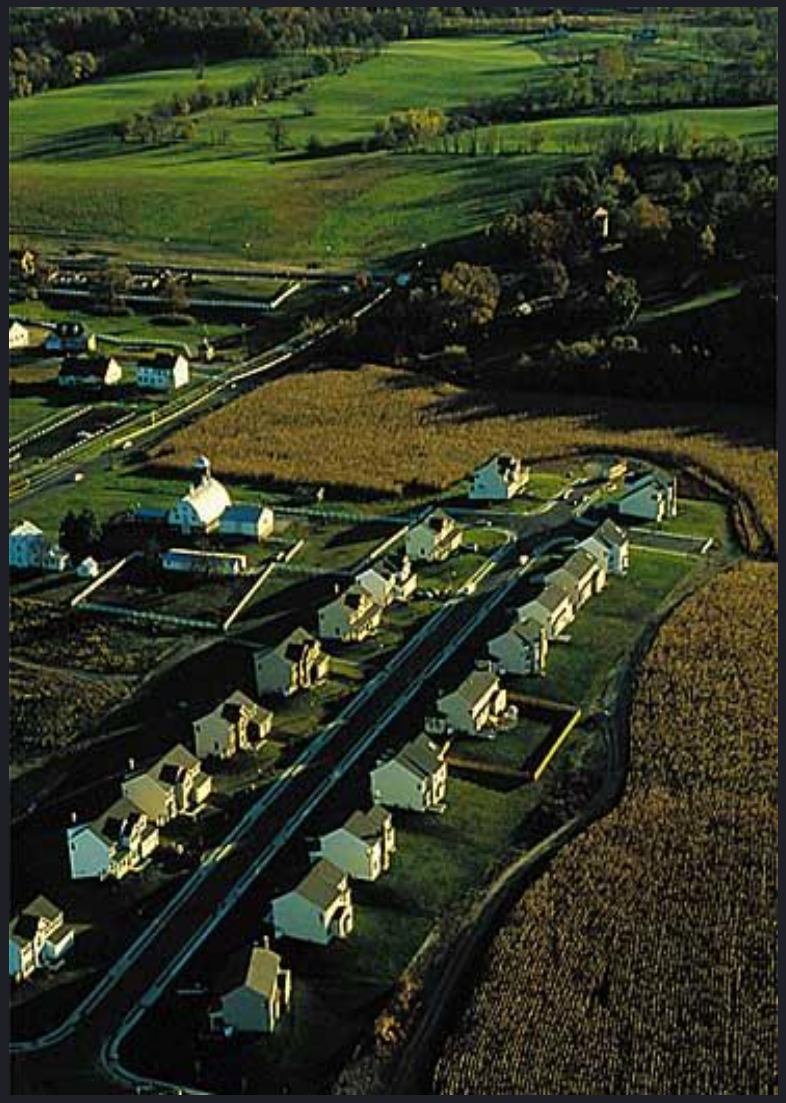
Introduction



How do urban processes contribute to global environmental change?

- How are humans changing the Earth?
- What are the drivers and implications of this change?
- How does the built environment affect energy use, carbon emissions, and climate?

New attention to urban areas in land use/land cover research

- Can urban development strategies be aligned with climate change adaptation?
- How can urban planning tools be used to develop more resilient cities?

Introduction

Understanding urbanization in China and the Monsoon Asia region

- Monitoring urban systems and land patterns regionally-globally using satellite data
- Local case-study analysis of geographically comprehensive sample of cities
- Predictive modeling, forecasting of dynamic socio-economic forces and land-based outcomes

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Introduction

Tremendous opportunity to shape the built environment

Majority of urban development on the ground by 2050 in China *will be built between now and then*

Single-family home and ‘villa’ development – new trends in China

Urbanization in China

Policy reforms

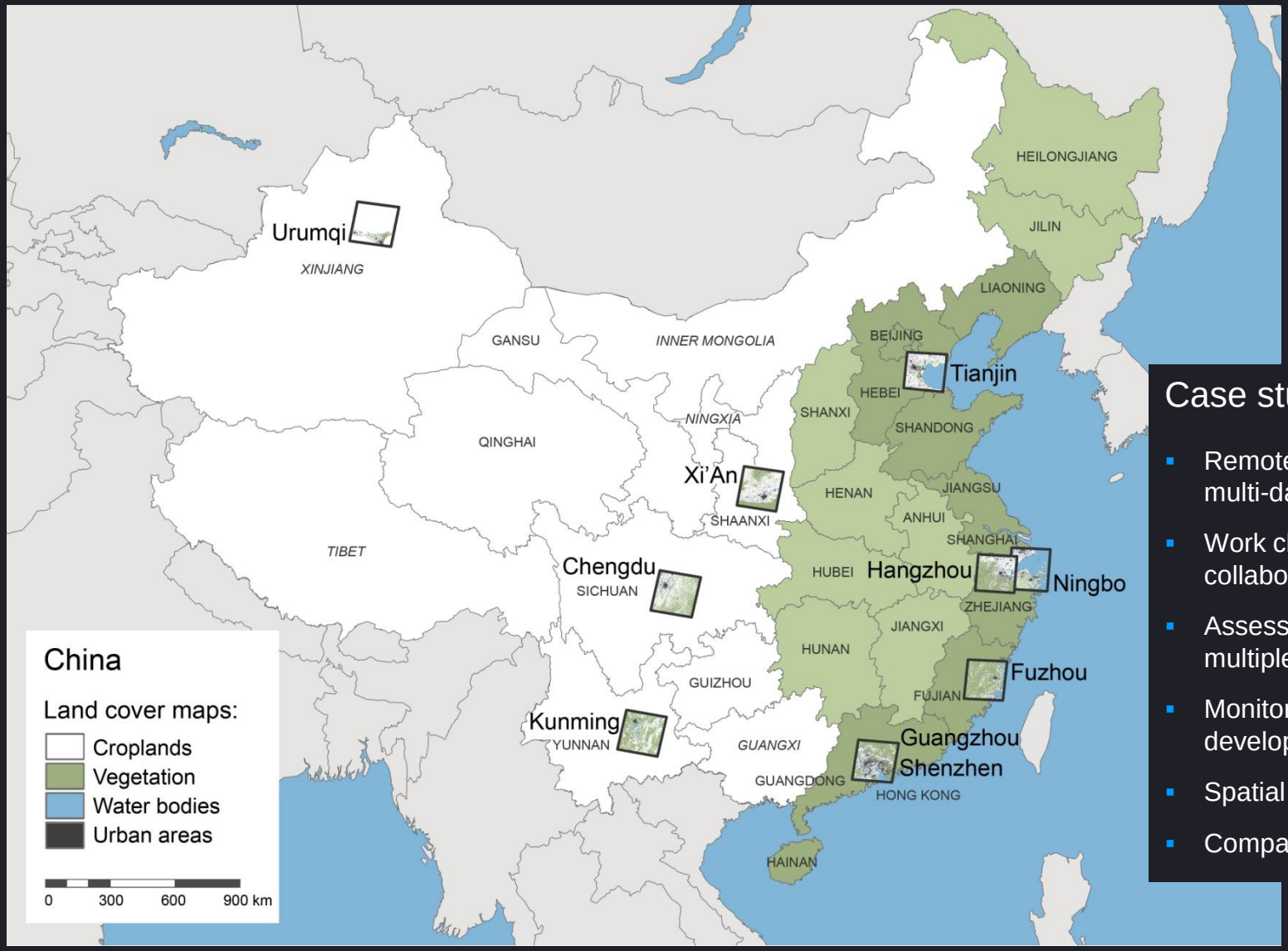
- 1978 economic, land reforms: decentralization, land use rights, liberalization of household registration system (*hukou*) and work unit (*danwei*)
- 1990s great western development program
- 2001 new emphasis on villages

Impacts?

- Rapid rural-urban migration
- Rapid land use change
- Agricultural expansion, intensification
- GDP 1978-2008: 8-14%
- Increase in income - vehicles, housing, diet

Photos: A. Perlstein

Urban expansion in China

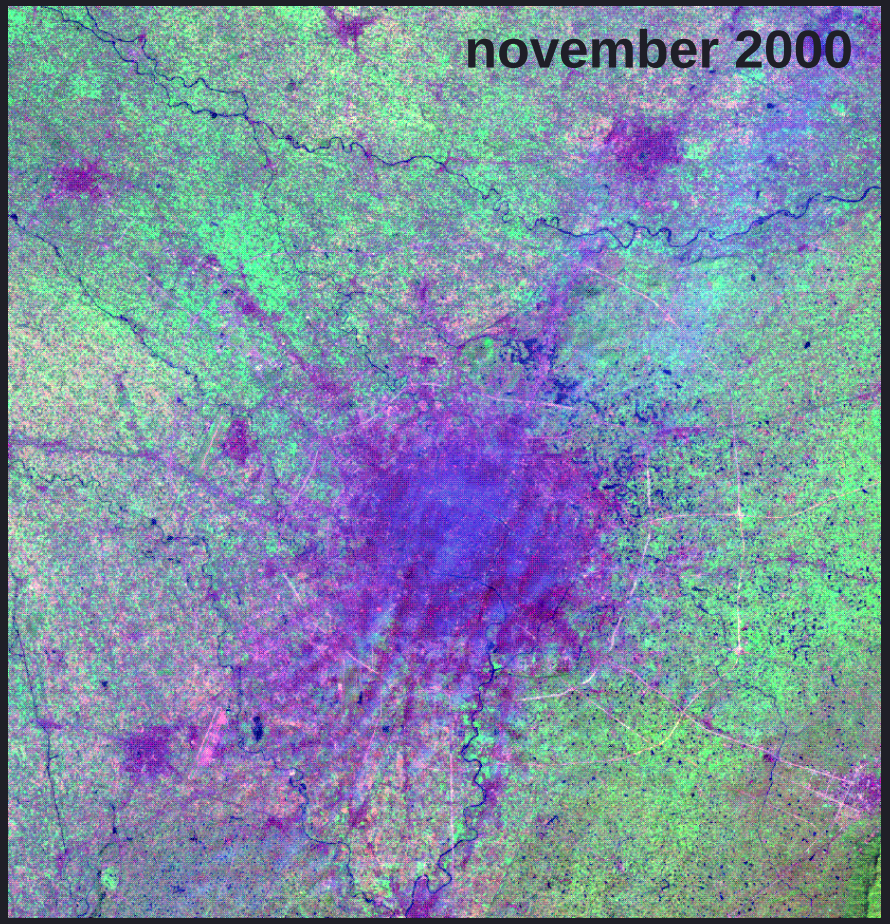


Case study methods

- Remote sensing - multi-date change detection
- Work closely with collaborators, contacts
- Assess trajectory of multiple time points
- Monitor peri-urban, village development
- Spatial analysis
- Compare east vs. west

Remote sensing methods

Numerous change detection methods, 30 year history



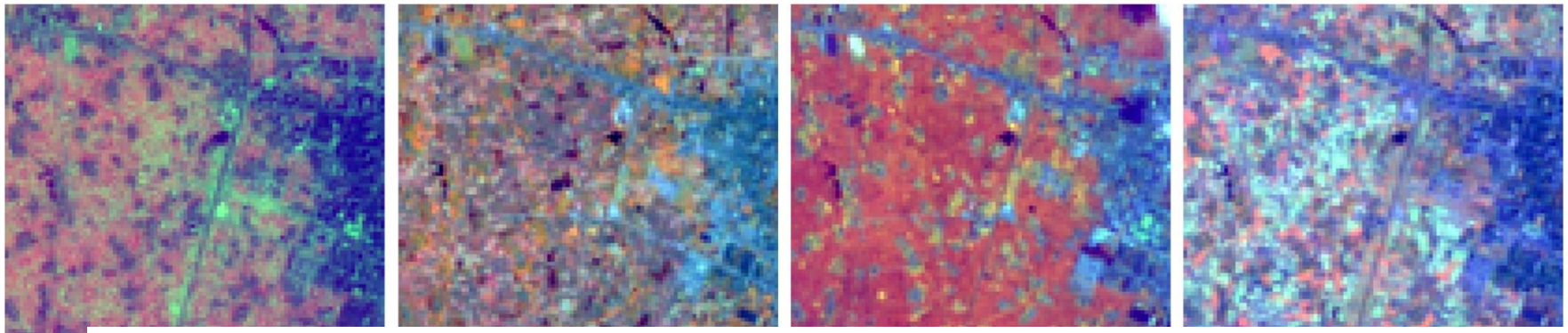
Common problems

- Complexity of landscape in SE Asia
- Confusion between new urban and bare agriculture plots
- Agricultural, vegetation variability

Choice of method:

- Supervised multi-date classification
- Multi-temporal, **multi-seasonal** approach
- Dense time stacks of Landsat data
- Training examples: ***stable*** and ***changed*** classes
- Accuracy assessment

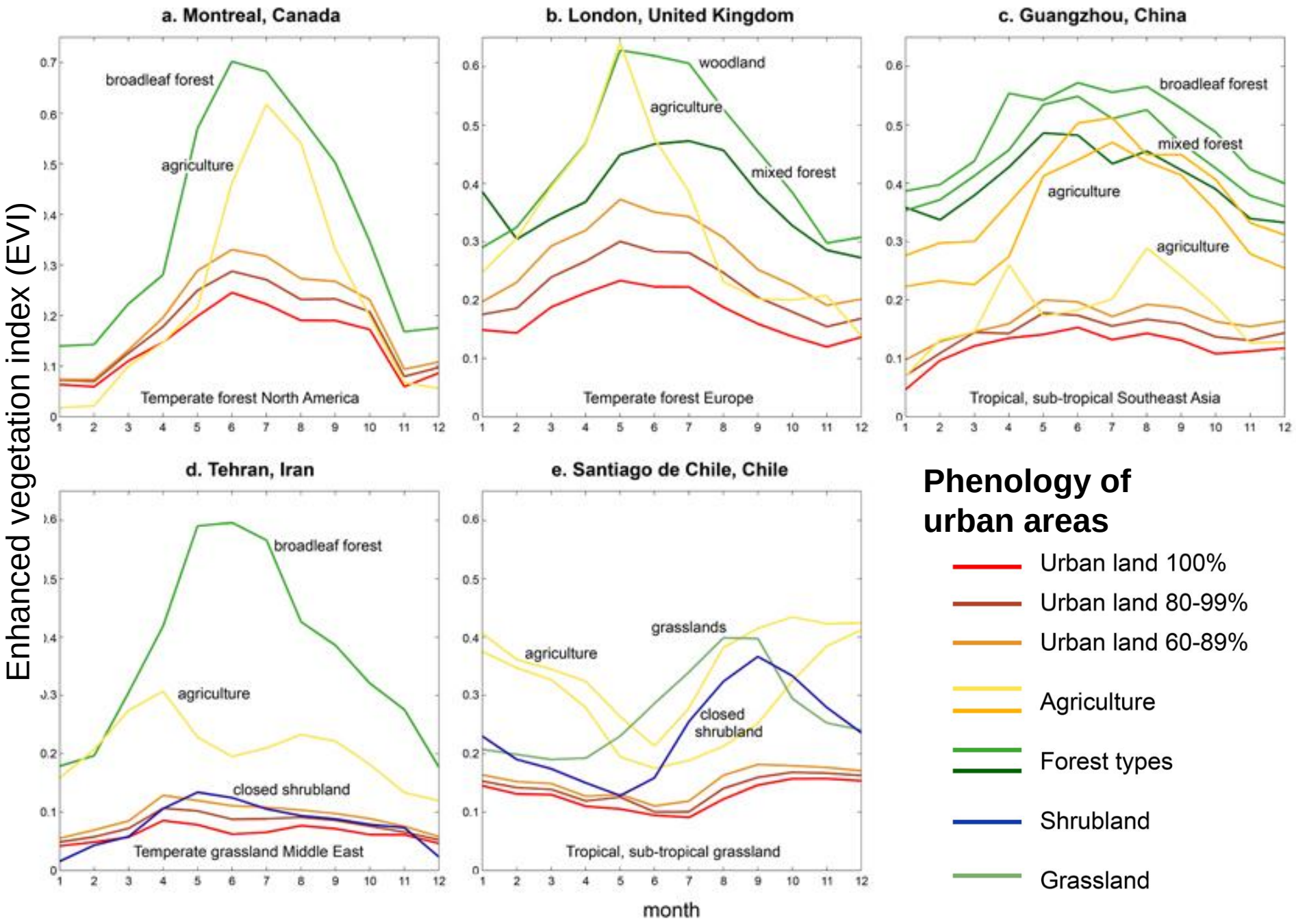
Dense time stacks of Landsat data



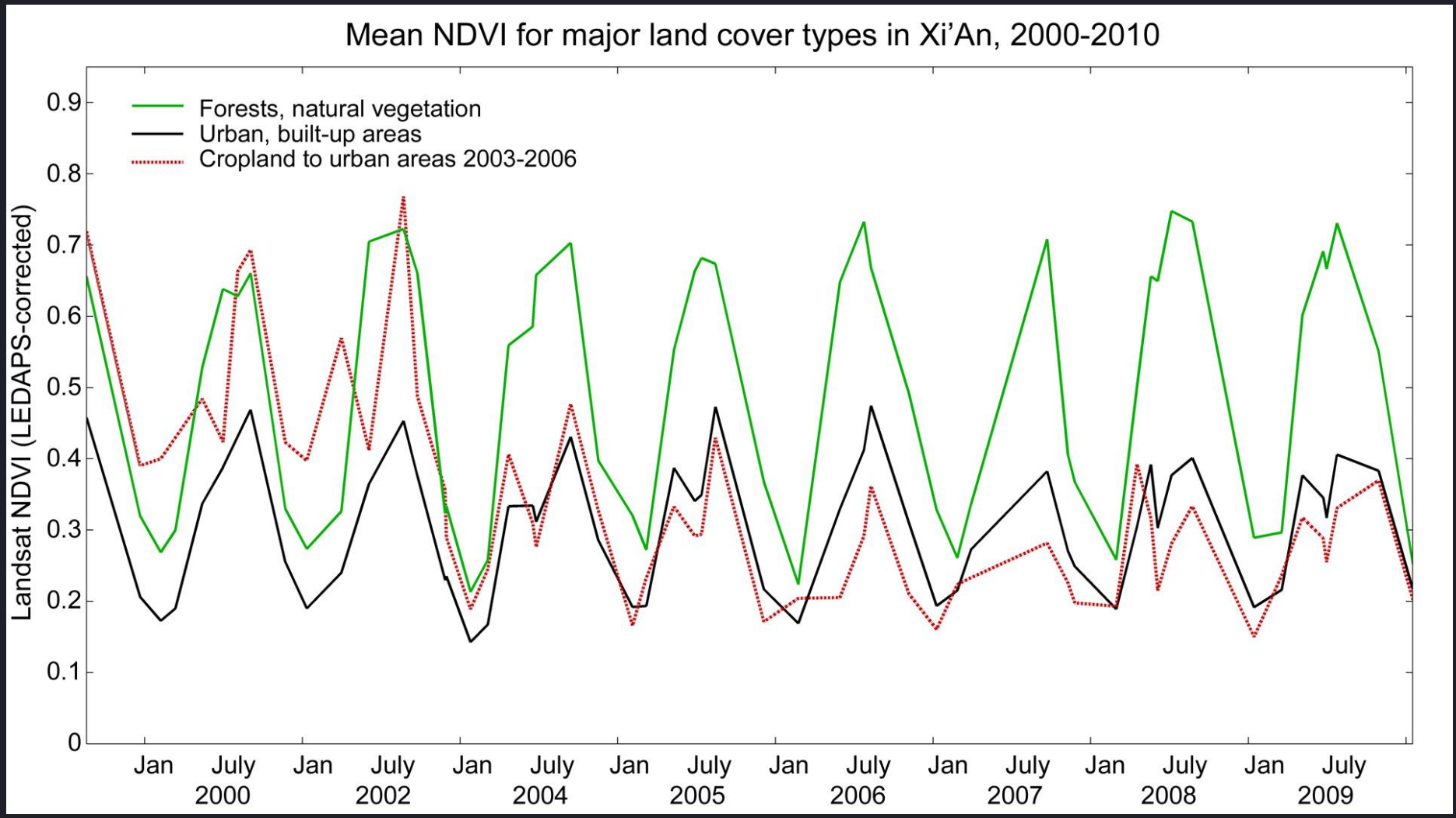
Kunming	1980s		1990s										2000s										
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
January														01-21			01-30		01-03		01-09		01-30
February													02-20	02-23	02-09	02-28		02-09	02-20	02-23		02-12	02-15
March		03-09											03-23				03-02	02-25	03-08	03-11	03-29		03-19
April		03-25						04-03[a]					04-24		04-30			04-06	04-01			04-17	
May																	05-21		05-19				05-06
June														06-14								06-04	
July																							
August					08-16																		
September													09-15					09-13		09-19			
October															10-07								
November													11-02	11-21					11-03		11-08	11-11	
December														12-23					11-27		12-10	12-29	

Table key: Landsat 5 TM data | Landsat 7 ETM data | Landsat 7 ETM scan line corrector-off data

Sample Landsat dense time series for Kunming, 50 images 1988-2009


a. Montreal, Canada
broadleaf forest
agriculture
Temperate forest North America
b. London, United Kingdom
woodland
agriculture
mixed forest
Temperate forest Europe
c. Guangzhou, China
broadleaf forest
mixed forest
agriculture
agriculture
Tropical, sub-tropical Southeast Asia
d. Tehran, Iran
broadleaf forest
agriculture
closed shrubland
Temperate grassland Middle East
e. Santiago de Chile, Chile
grasslands
agriculture
closed shrubland
Tropical, sub-tropical grassland
Enhanced vegetation index (EVI)
month
Phenology of urban areas
Urban land 100%
Urban land 80-99%
Urban land 60-89%
Agriculture
Forest types
Shrubland
Grassland

Seasonal trajectories of land cover types



Multi-year NDVI trajectories derived from atmospherically-corrected Landsat data (LEDAPS, Masek, 2007).

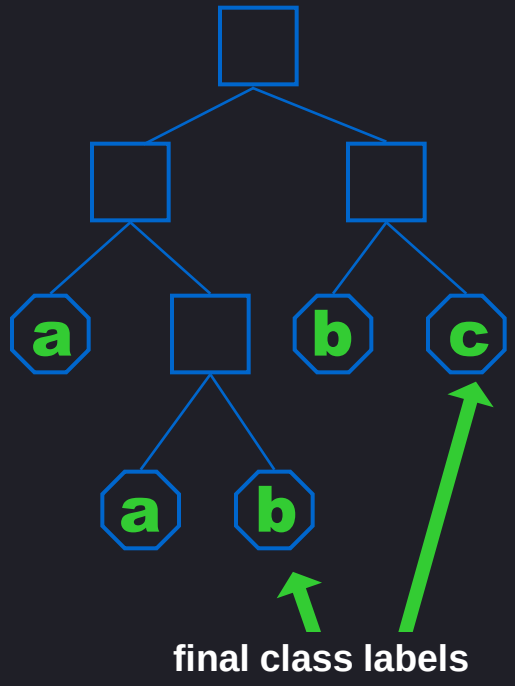
Remote sensing methods

1. Which supervised classification algorithm performs the best given complex, dense temporal stacks?

   - Traditional maximum likelihood classifier
   - Boosted decision trees (C4.5)

     recursive partitioning of training data into successively more homogeneous subsets based on entropy
   - Support vector machines (libSVM)

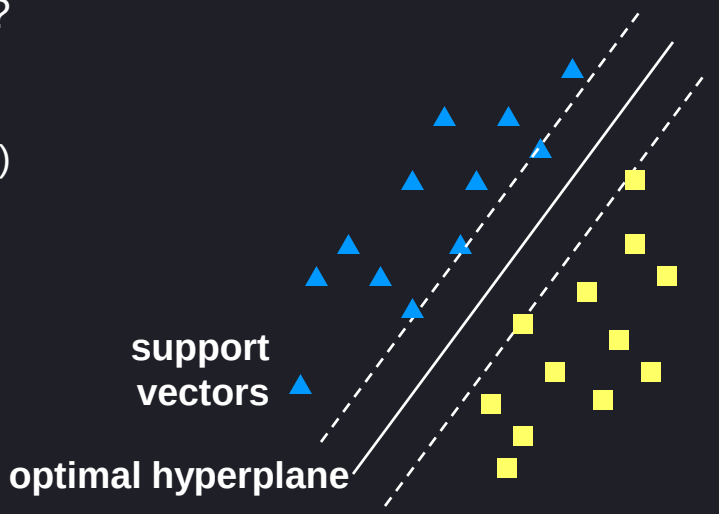
     optimal boundaries between classes are defined in feature space using optimization algorithms



2. Can feature selection lead to greater map accuracy?

   - 40-55 scenes, uncorrected Landsat data
   - Additional inputs: NDVI, min, max, mean of each band)

3. How well do multi-temporal approaches work in peri-urban environments given the small size of settlements?



Characterizing urban expansion

How do we map changes in urban areas with satellite data?

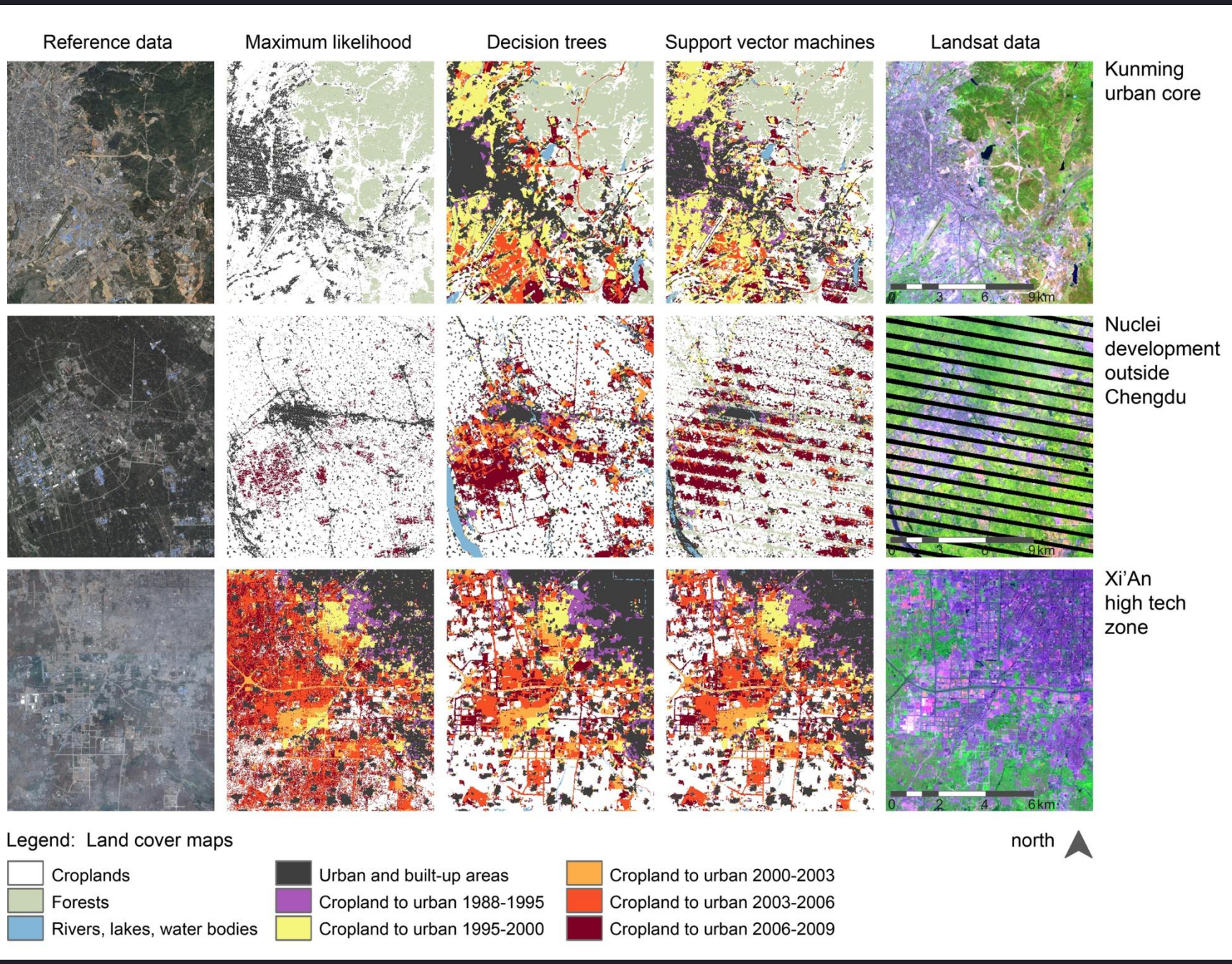
- Extremely difficult with medium resolution data
- Training site collection revolutionized by Google Earth, availability of time series VHR imagery
- Development of cross-platform methods

Results

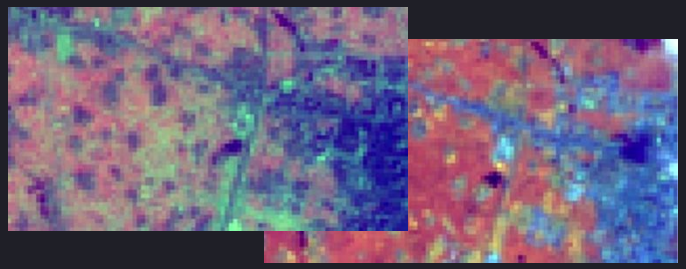
Accuracy assessment – algorithm performance

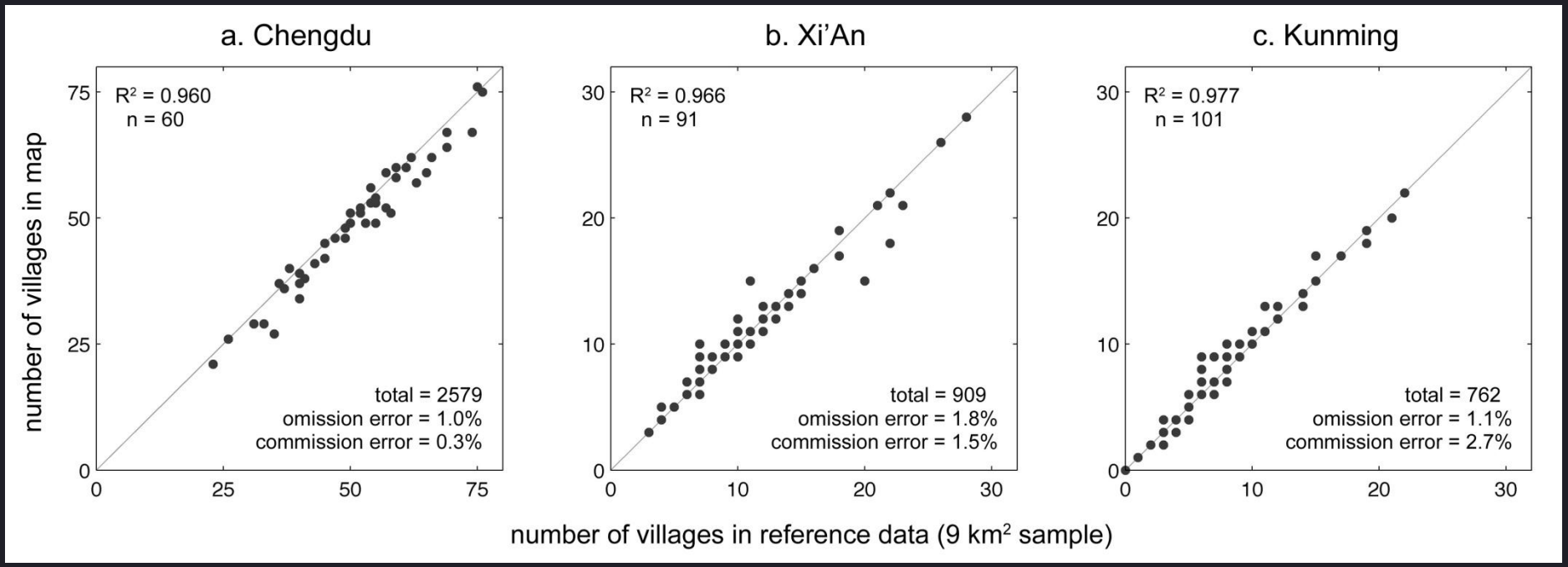
- Cross-validation approach using tenfold 80/20 splits
- Decision trees and SVM outperform traditional max likelihood
- Decision trees and SVM perform equally well (statistically speaking)
- Additional data inputs caused small increase in accuracy

	Chengdu		Xi'An		Kunming	
Overall accuracy results						
a. Maximum likelihood						
all landsat bands	56.3	*(1.6)*	76.1	*(0.6)*	68.6	*(1.1)*
all landsat, all ndvi	53.4	*(1.5)*	74.9	*(1.0)*	68.2	*(1.7)*
all landsat, all metrics	48.9	*(2.1)*	73.4	*(1.5)*	67.7	*(1.2)*
all landsat, ndvi, metrics	51.4	*(1.5)*	74.5	*(0.9)*	68.7	*(0.9)*
all landsat, no slc-off	67.9	*(1.4)*	**89.4**	*(0.6)*	63.6	*(24.2)*
all ndvi	71.8	*(1.3)*	84.1	*(0.7)*	**76.8**	*(0.7)*
all ndvi, all metrics	**74.6**	*(1.8)*	86.6	*(1.2)*	71.3	*(17.7)*
b. Decision trees						
all landsat bands	85.5	*(0.7)*	93.0	*(0.6)*	91.1	*(0.9)*
all landsat, all ndvi	88.1	*(0.9)*	93.6	*(0.7)*	91.7	*(1.0)*
all landsat, all metrics	88.0	*(0.6)*	93.7	*(0.7)*	91.9	*(0.8)*
all landsat, ndvi, metrics	**89.8**	*(0.8)*	**93.8**	*(0.6)*	**92.9**	*(0.4)*
all landsat, no slc-off	75.6	*(1.4)*	91.8	*(0.3)*	86.7	*(0.7)*
all ndvi	77.5	*(1.1)*	91.0	*(0.9)*	86.7	*(0.7)*
all ndvi, all metrics	82.6	*(0.8)*	93.2	*(0.5)*	91.2	*(0.7)*
c. Support vector machines						
all landsat bands	90.0	*(1.3)*	93.9	*(0.8)*	92.5	*(0.6)*
all landsat, all ndvi	89.3	*(0.7)*	**94.1**	*(0.5)*	92.8	*(0.8)*
all landsat, all metrics	**91.0**	*(0.7)*	93.8	*(0.6)*	92.9	*(0.7)*
all landsat, ndvi, metrics	**90.9**	*(0.8)*	**94.1**	*(0.7)*	**93.0**	*(0.8)*
all landsat, no slc-off	79.5	*(1.0)*	91.5	*(0.5)*	87.8	*(0.4)*
all ndvi	76.1	*(1.1)*	90.2	*(0.9)*	84.4	*(1.2)*
all ndvi, all metrics	84.0	*(0.9)*	93.4	*(0.7)*	90.9	*(0.5)*


Reference data
Maximum likelihood
Decision trees
Support vector machines
Landsat data
Kunming urban core
Nuclei development outside Chengdu
Xi'An high tech zone
0 3 6 9km
0 3 6 9km
0 2 4 6km
Legend: Land cover maps
Croplands
Forests
Rivers, lakes, water bodies
Urban and built-up areas
Cropland to urban 1988-1995
Cropland to urban 1995-2000
Cropland to urban 2000-2003
Cropland to urban 2003-2006
Cropland to urban 2006-2009
north

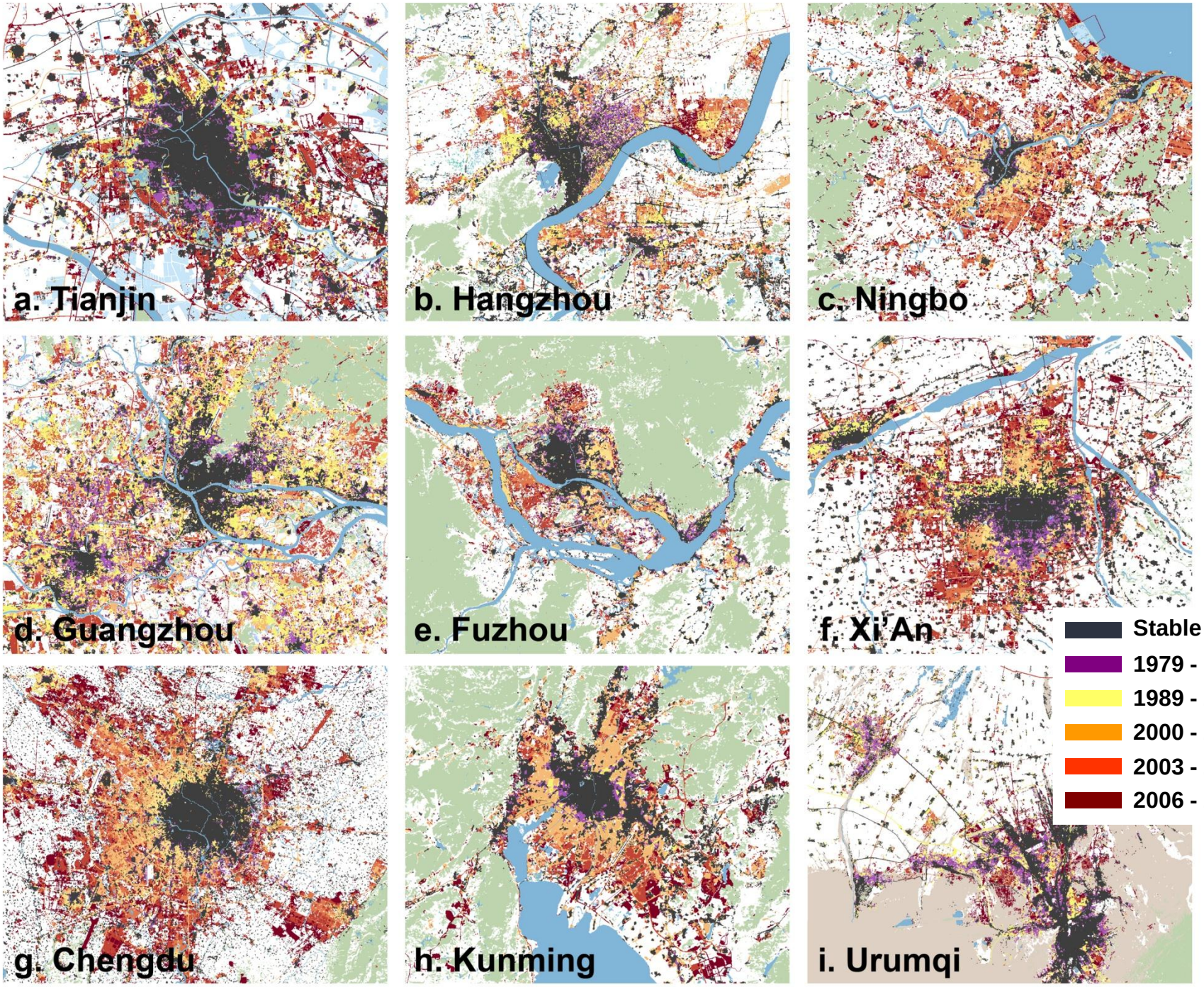
Monitoring peri-urban development



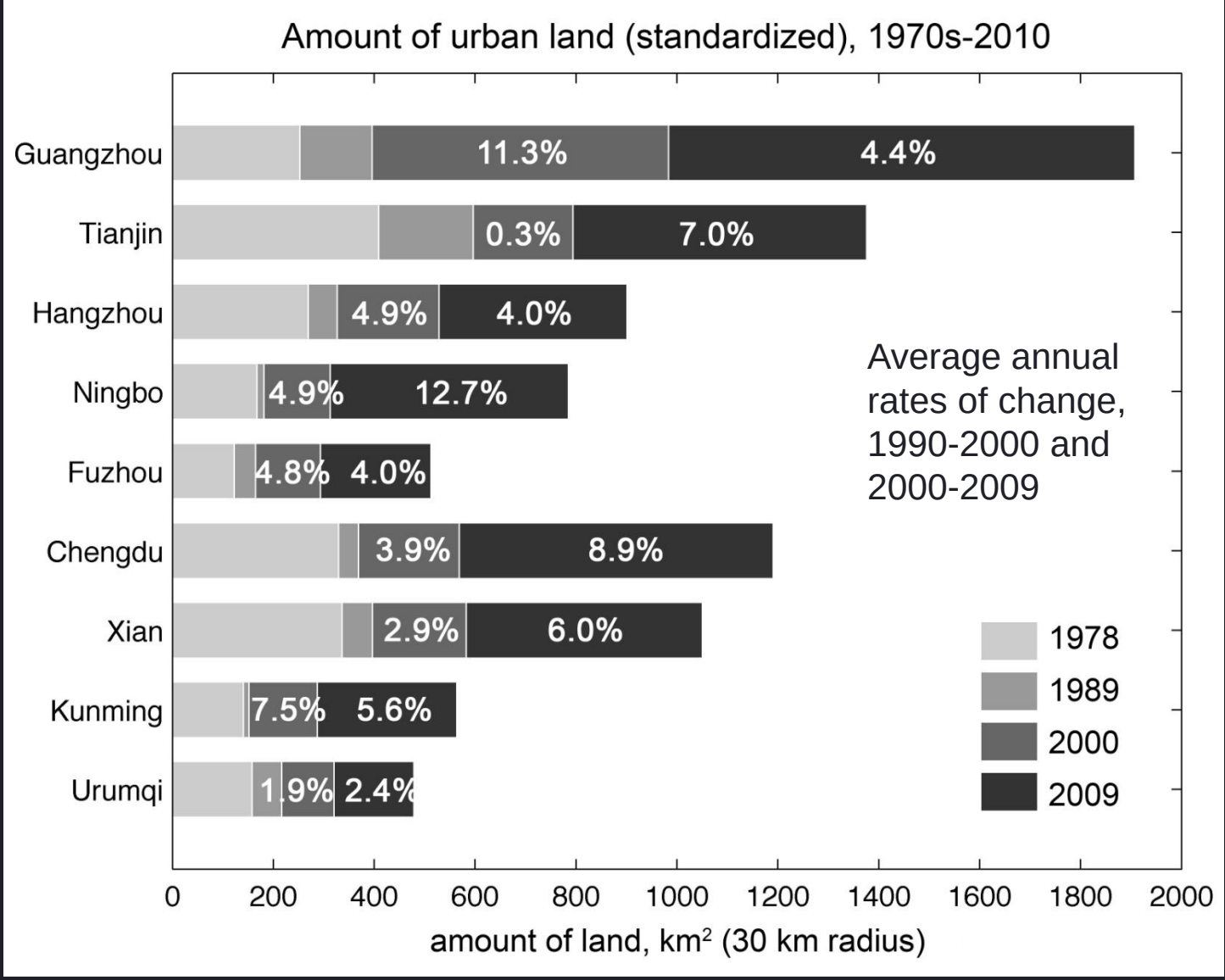


Assessing classifier performance in peri-urban areas

- Sample of 60-100 9 km^2 sites in each study area, capturing 700-2600 settlements
- Simple presence/absence of settlement determined from Google Earth
- Results show omission and commission errors < 2%

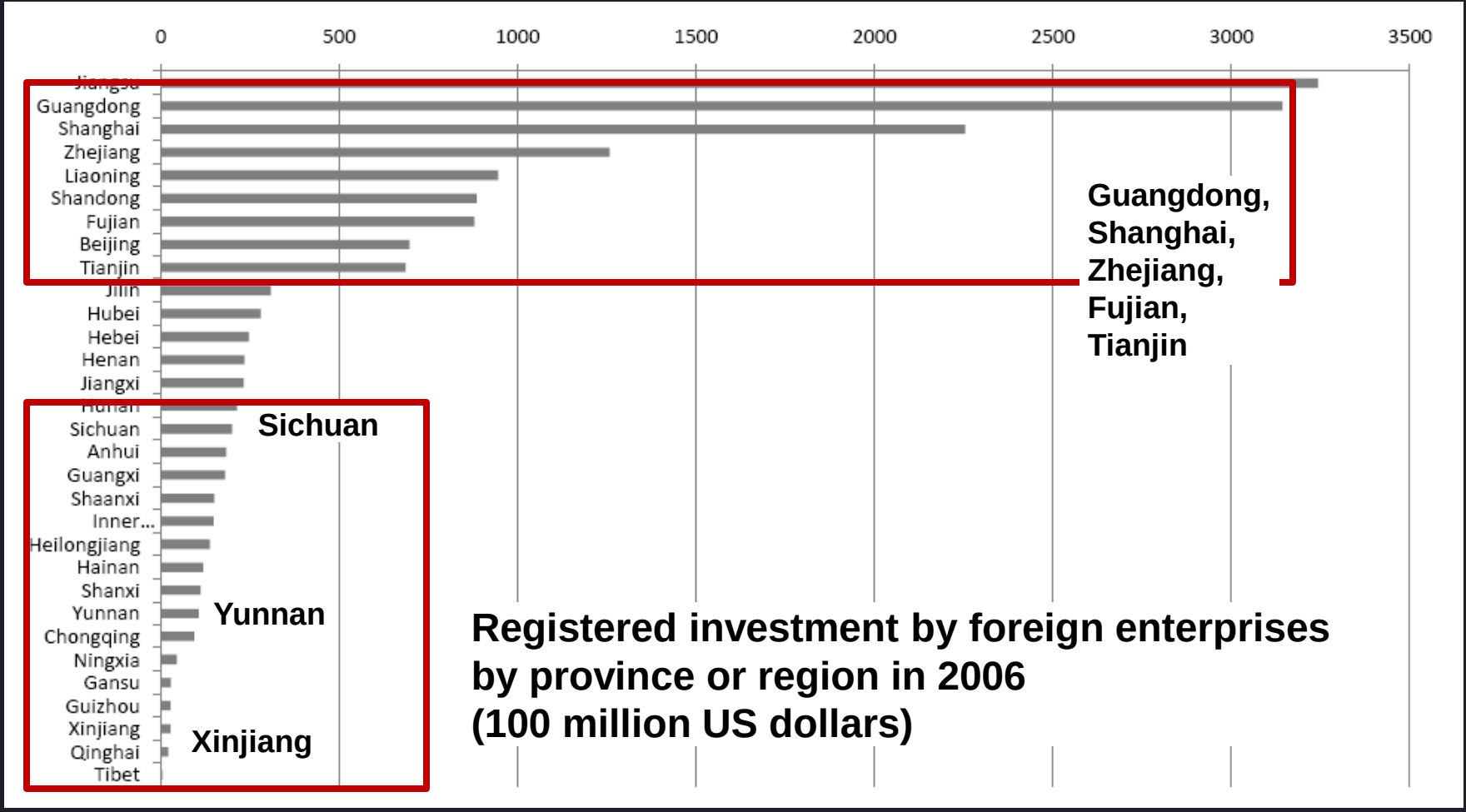

a. Tianjin
b. Hangzhou
c. Ningbo
d. Guangzhou
e. Fuzhou
f. Xi'An
g. Chengdu
h. Kunming
i. Urumqi
Stable urban
1979 - 1989
1989 - 2000
2000 - 2003
2003 - 2006
2006 - 2009

Results – waves of urban expansion



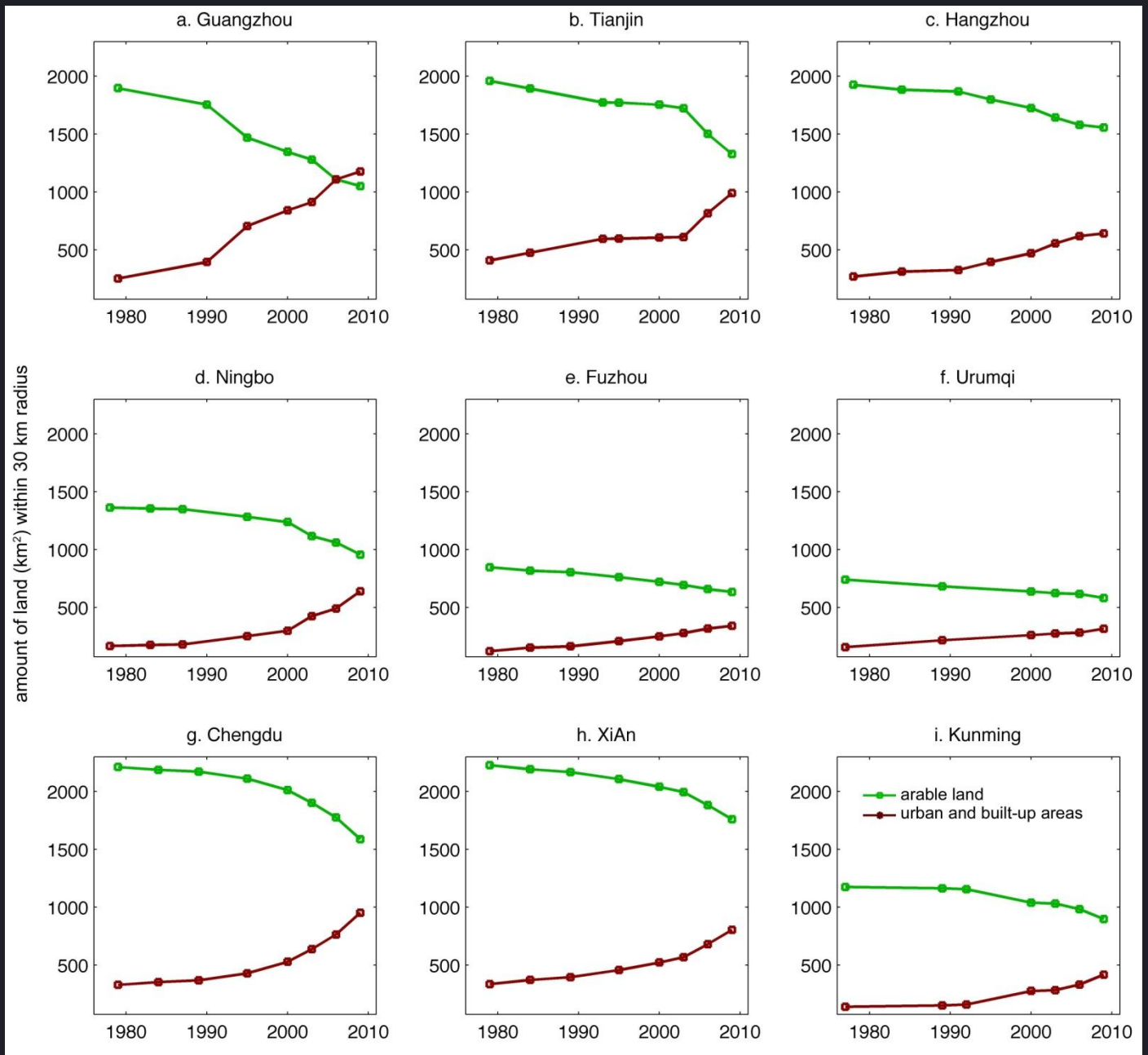
Results - rapid rates of expansion

Amounts, rates of land use change in western cities are approaching levels witnessed in coastal cities, although role of planning and FDI differ



Perlstein et al., in review

Results - rapid expansion, loss of arable land

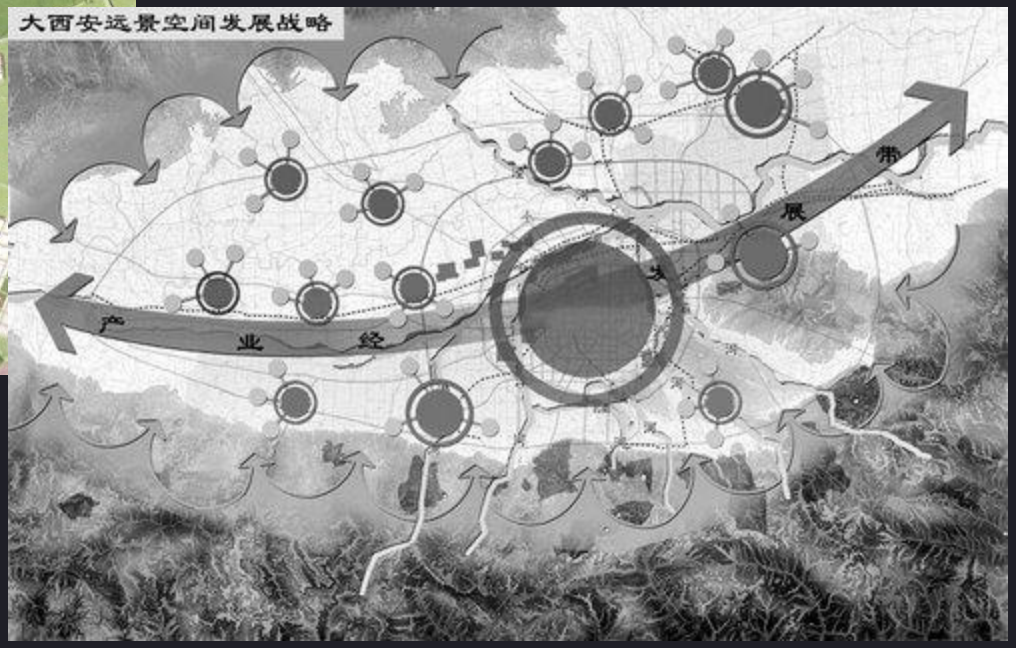


Results - planned nuclei growth

Urban expansion has been directed out of the central core to nearby towns, leading to *poly-nucleated urban form*

Chengdu regional plan

Xi'An regional plan



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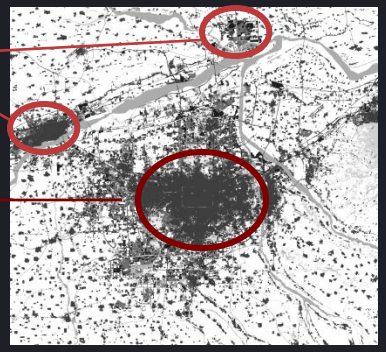
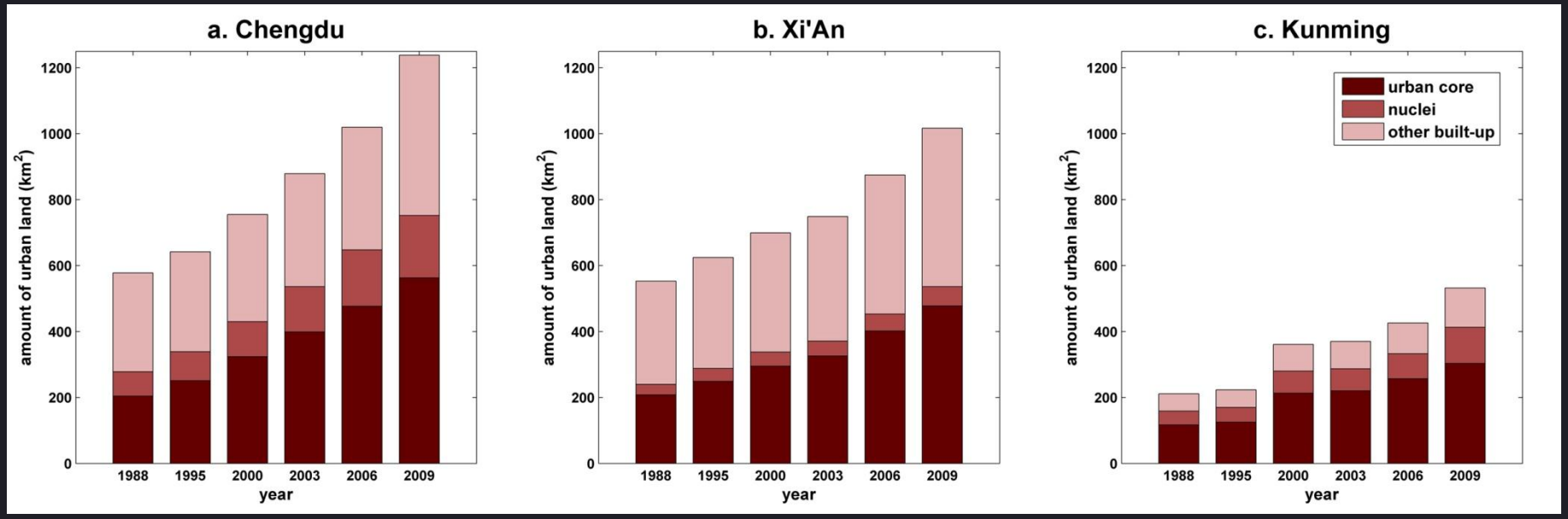


Simple measurement:

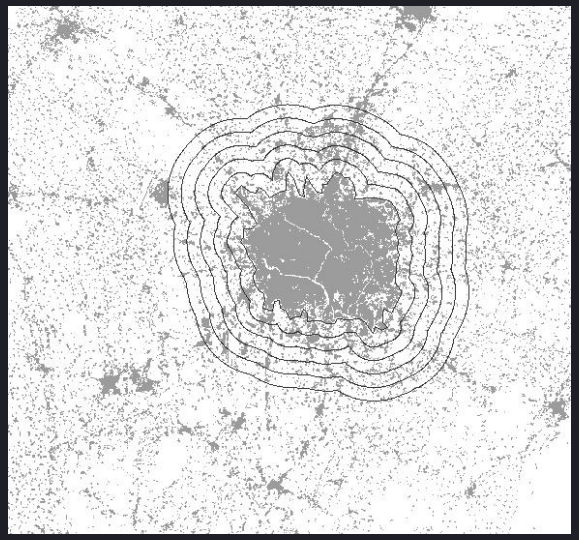
amount of urban land within core, nuclei at each time point



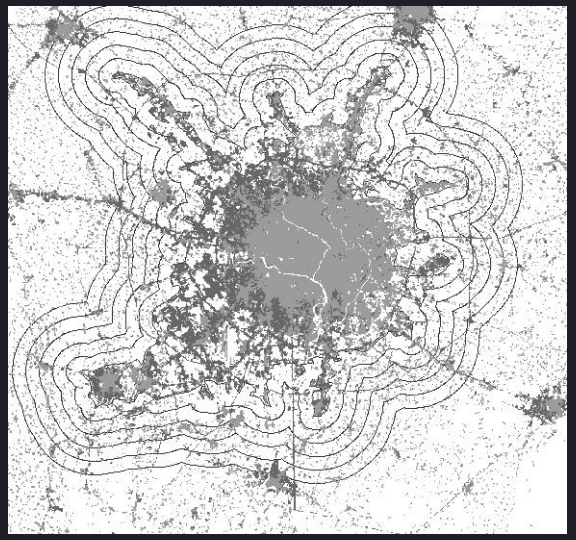
Results - planned expansion far from city

Urban expansion has been directed out of the central core to nearby towns, leading to *poly-nucleated urban form*

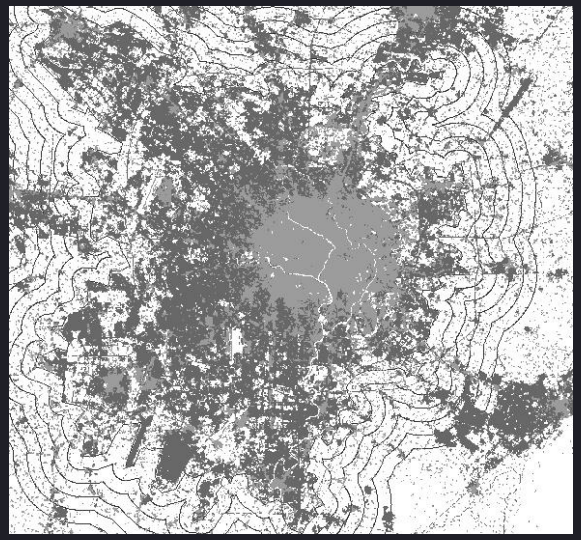
For each period, is development proximate to or far from existing urban land?



Chengdu 1988

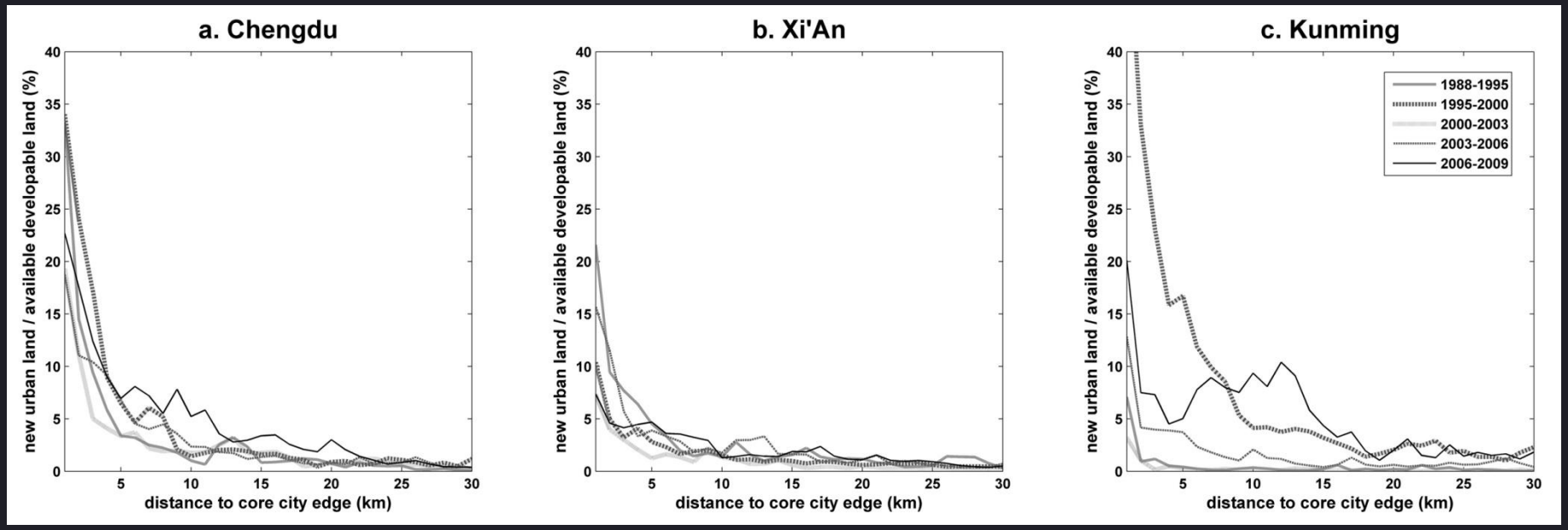


Chengdu 2000



Chengdu 2009

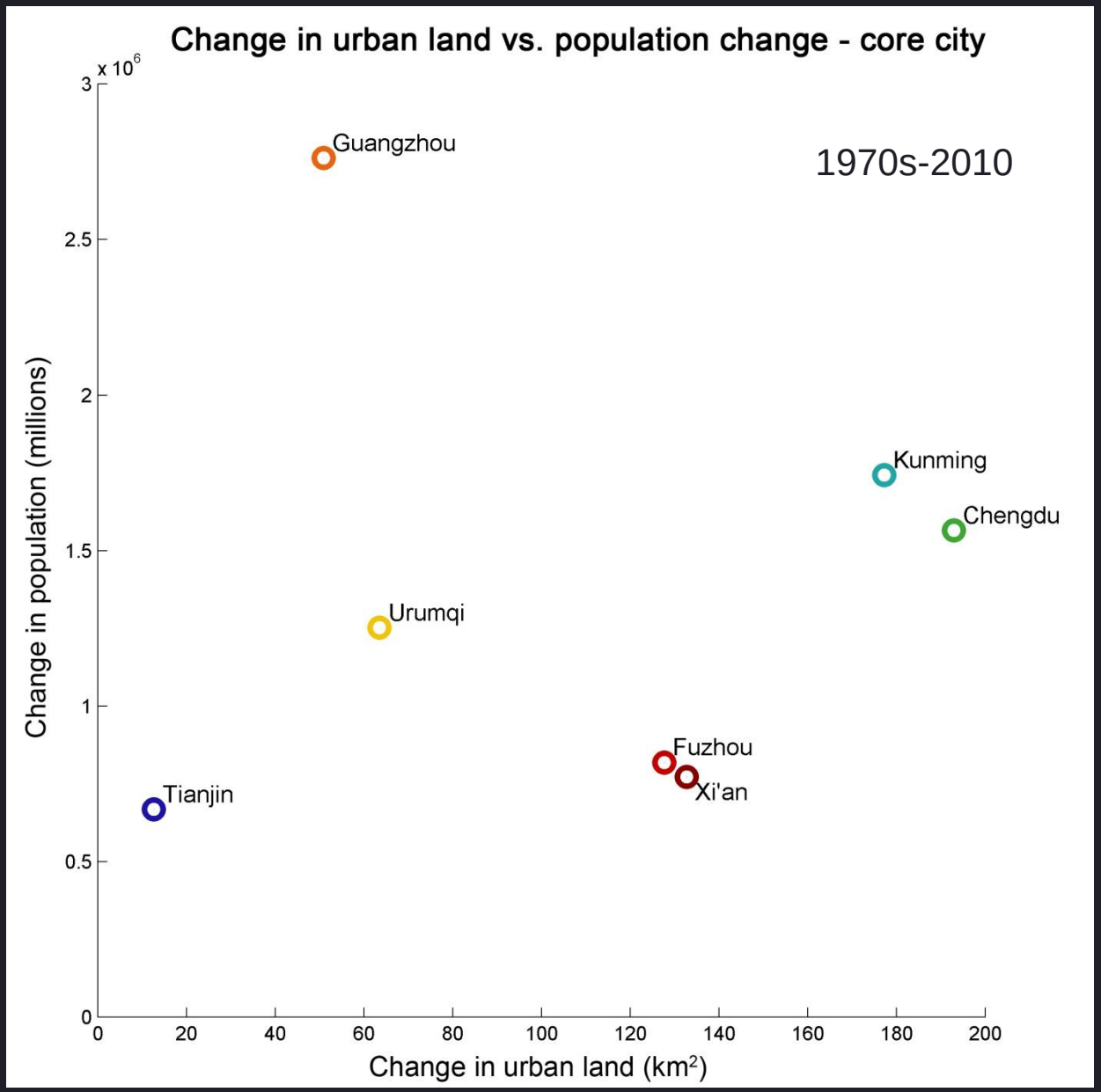
Results - planned expansion far from city



In later periods (2003-2006, 2006-2009),

urban expansion occurs farther from the city's edge (5-10 km)

Results – population change vs. expansion of urban land



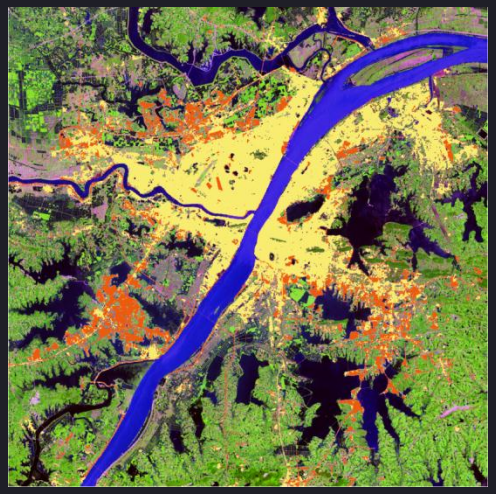
Conclusions

How are urban areas changing across China? How can we monitor rapid expansion across multiple time periods?

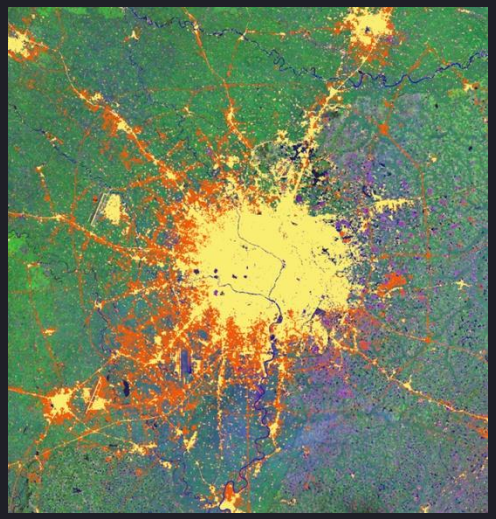
New era of remote sensing - increasing availability of VHR and multi-temporal datasets

Results show that urban expansion can be mapped successfully with dense time stacks of Landsat data

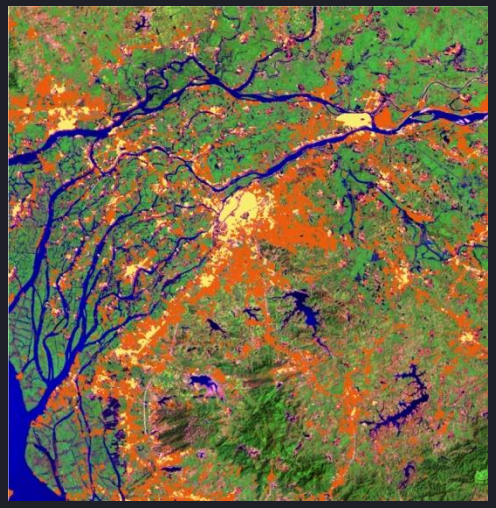
- Overall accuracy across cities - 90-94%
- DTs and SVMs perform equally well in terms of accuracy, but DTs perform better with respect to ***noisy, missing data***
- Feature selection produced mixed results, yet including NDVI and metrics showed modest accuracy increases (1-4%)
- High quality training data



Wuhan, Central China



Chengdu, Western China



Dongguan, Eastern China

Conclusions

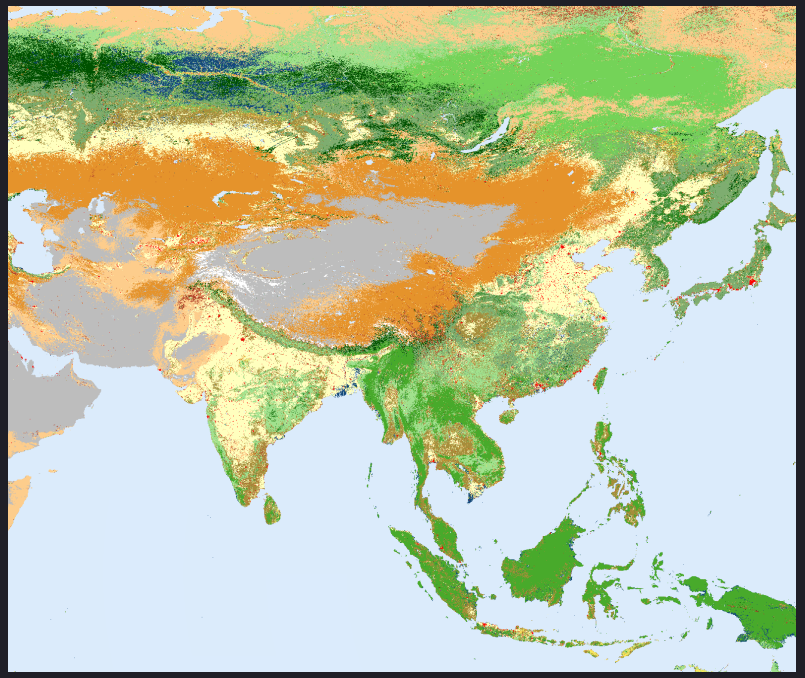
How are urban areas changing across China?
What are the drivers and implications of these changes?

Mapping urban land characteristics is
possible using medium resolution satellite data

Understanding urban spatial patterns is critical, but keep it simple!

Factors that affect urbanization are
multi-faceted, vary over space and time

- multi-scale planning
- preferential policy, zones
- foreign direct investment
- fiscal transfers
- road development
- economic transition
- migration



Acknowledgments

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