Multi-Sensor Analysis of Global Daytime and Nighttime Urban Heat Islands

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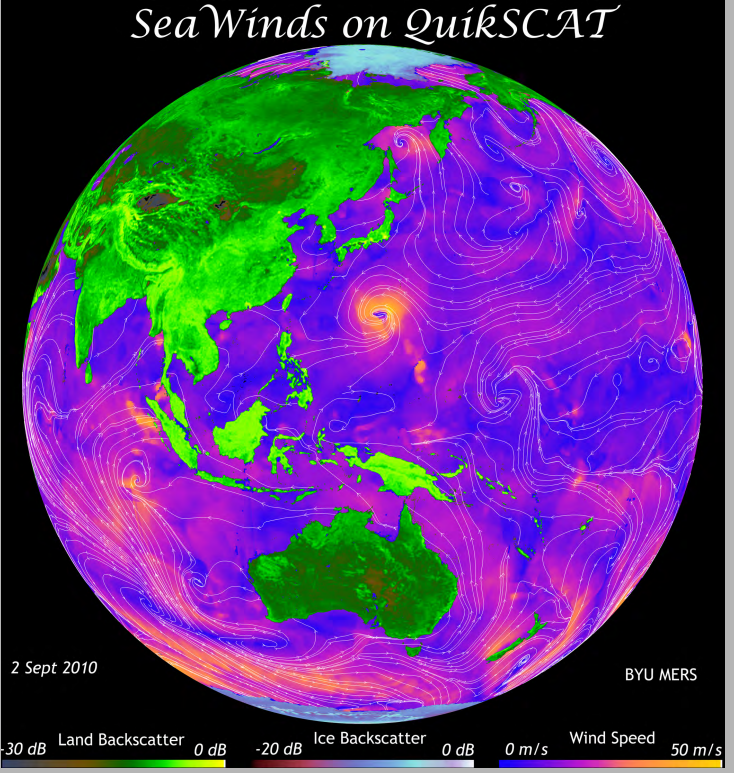
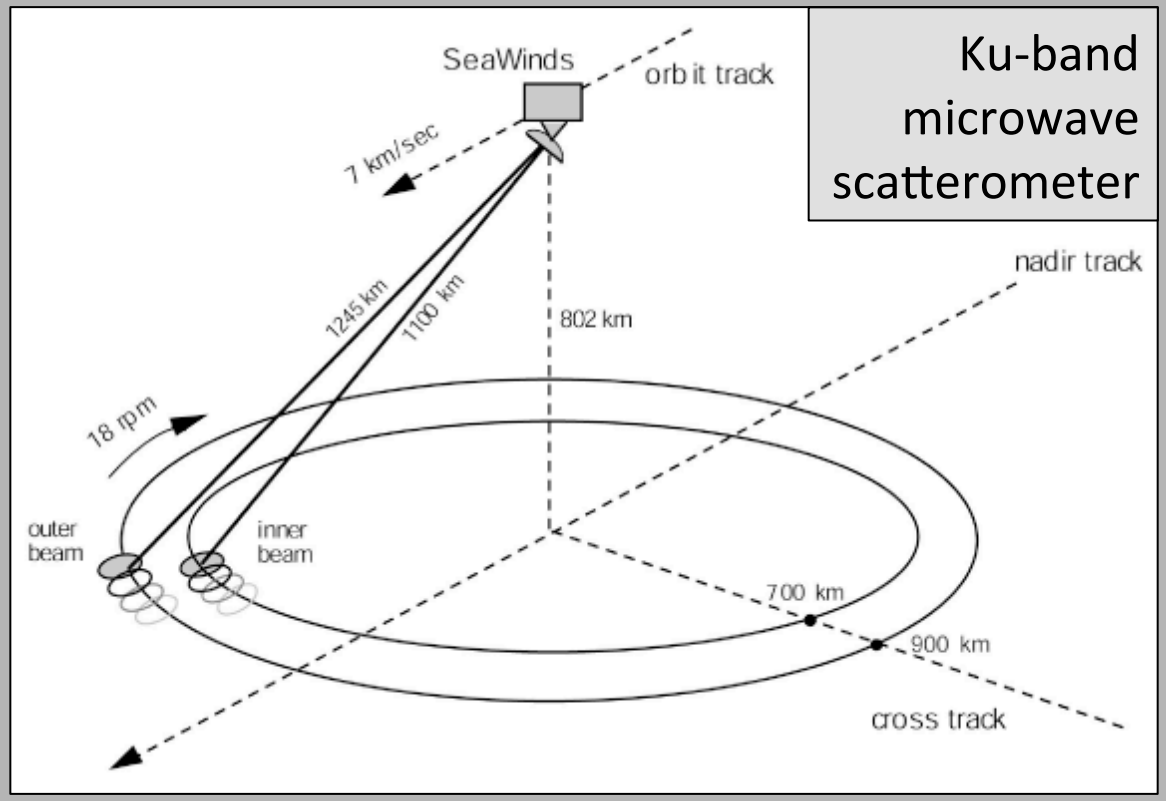
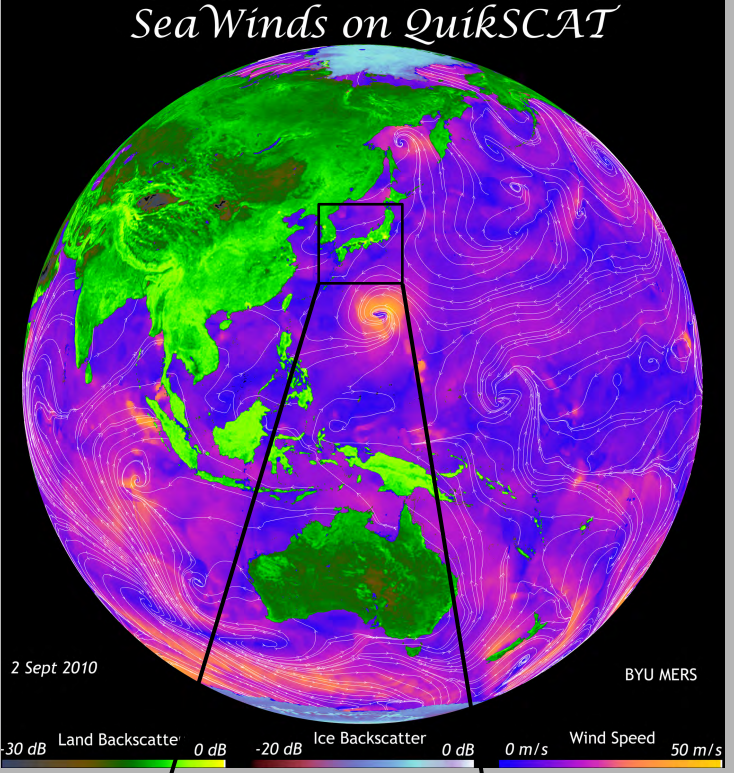
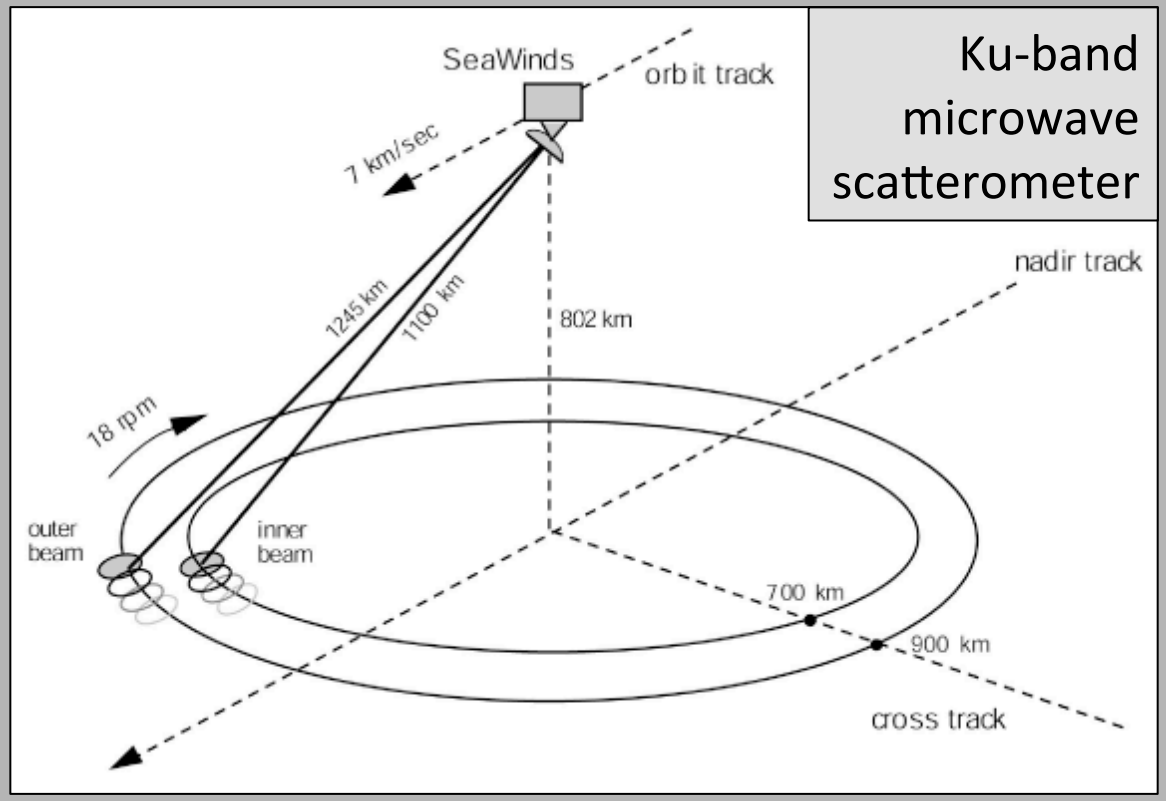


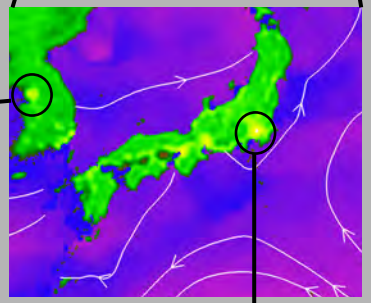
NASA Scatterometer Climate Pathfinder
D.Long, Brigham Young University



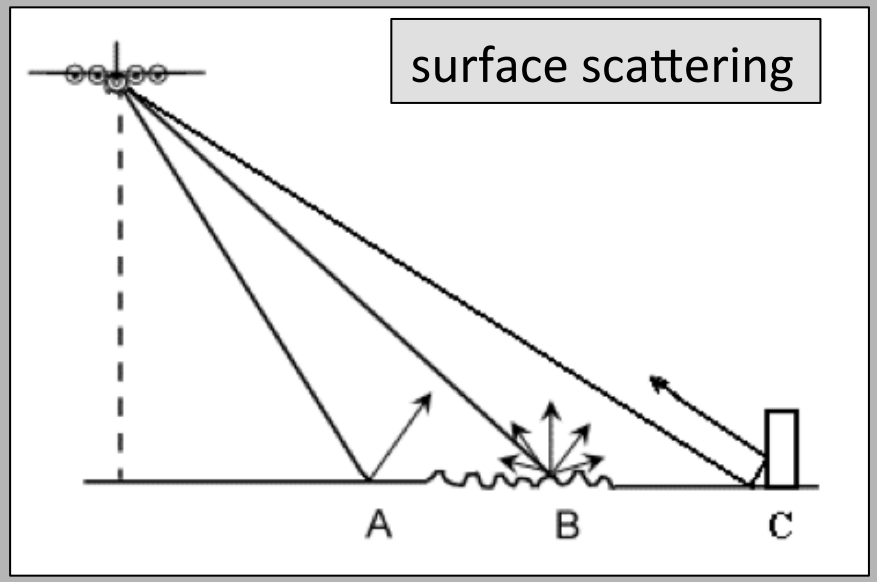
Ku-band microwave scatterometer







Big cities have strong backscatter.



A – specular reflection
B – diffuse scattering
C – corner reflector

1.3 million new urban residents per week globally until 2050

Essentially all population growth in the coming 3.5 decades.

Where is growth occurring? With what effect on urban structure?

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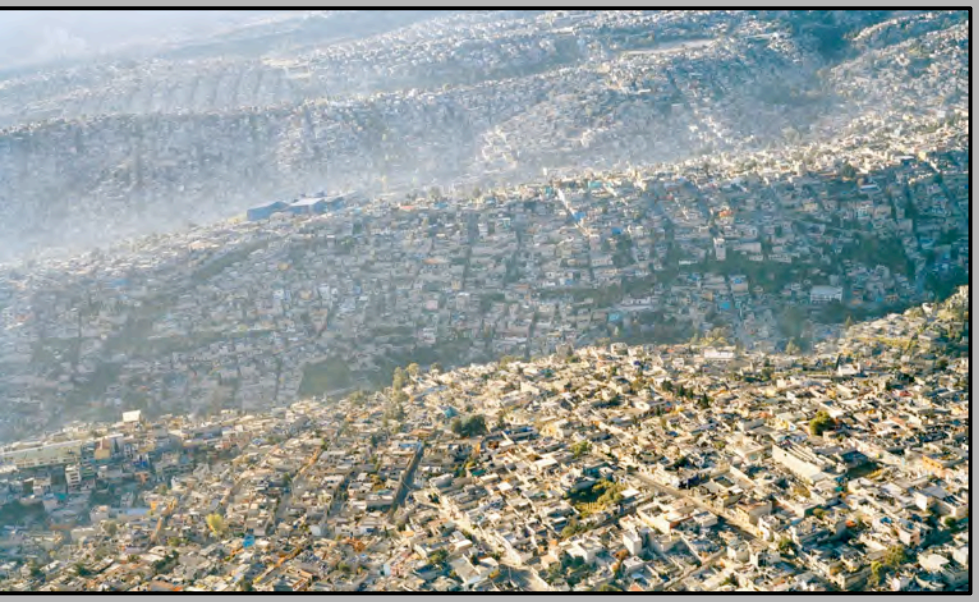
horizontal spread/sprawl



Mexico City; Photo: Pablo Lopez Luz

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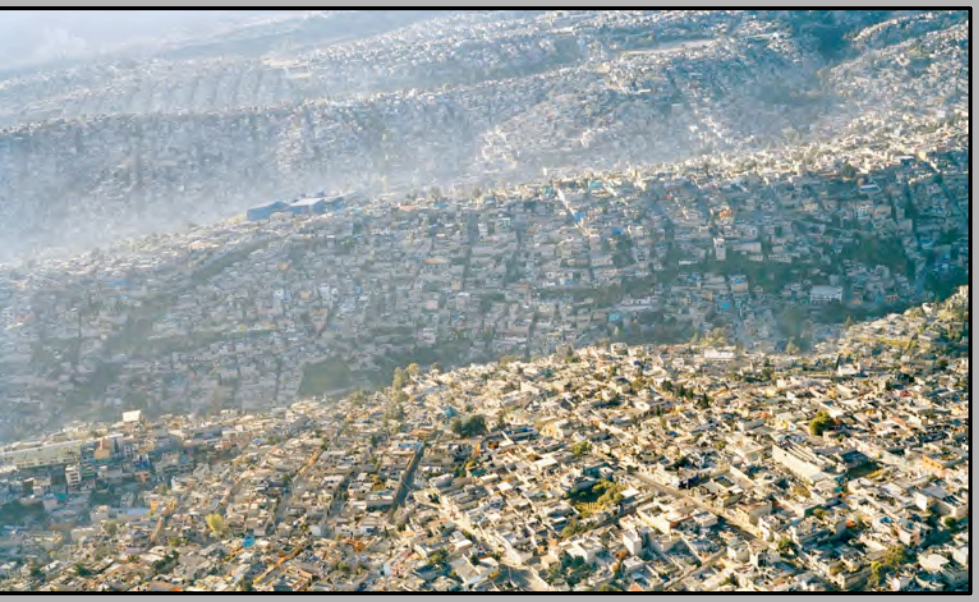
Where is growth occurring? With what effect on urban structure?

horizontal spread/sprawl -or- vertical rise/densification?



Mexico City; Photo: Pablo Lopez Luz

Chongqing, China; Photo : Matthew Niederhauser

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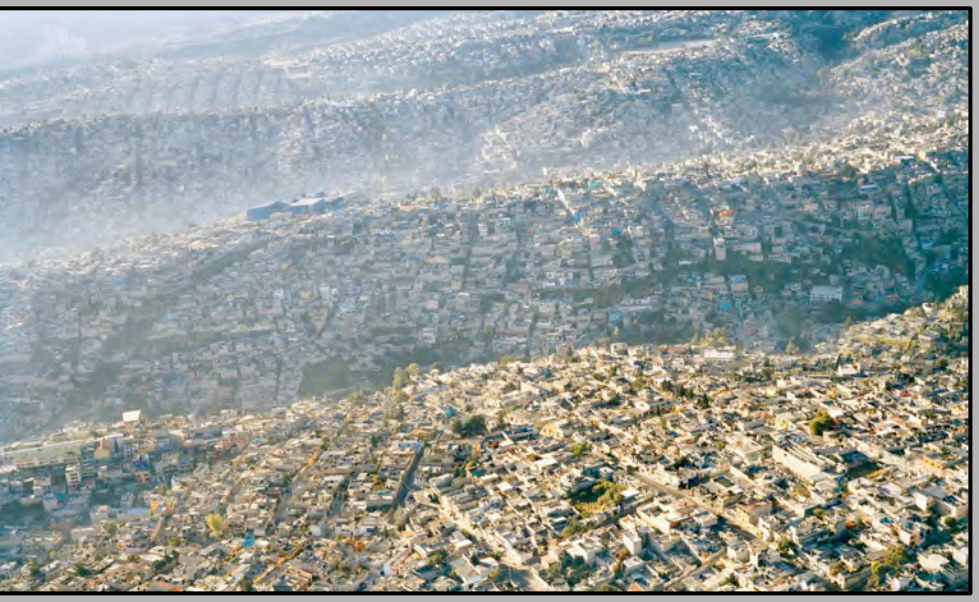


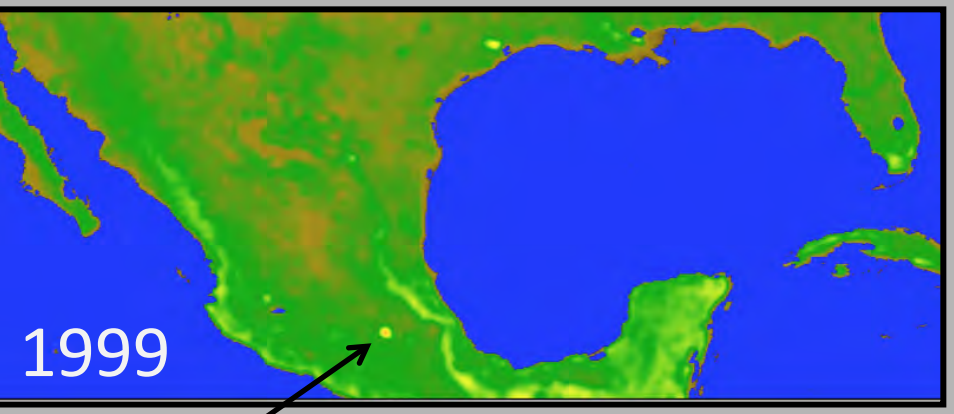
Mexico City; Photo: Pablo Lopez Luz

Chongqing, China; Photo : Matthew Niederhauser

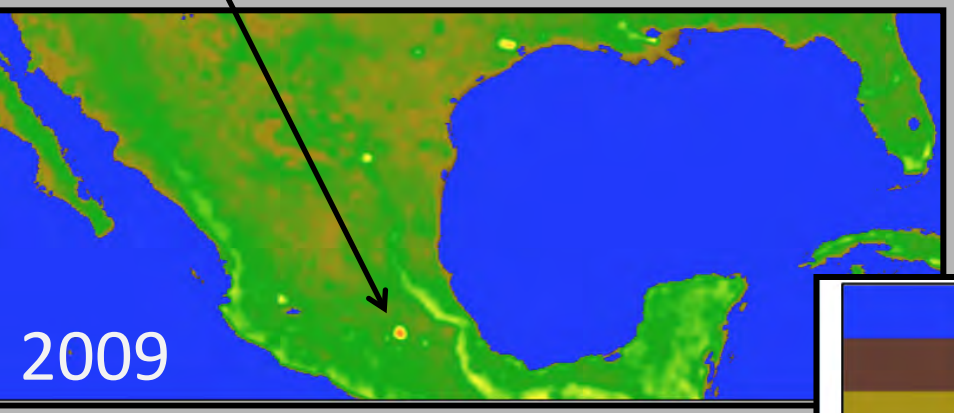
What are the consequences?

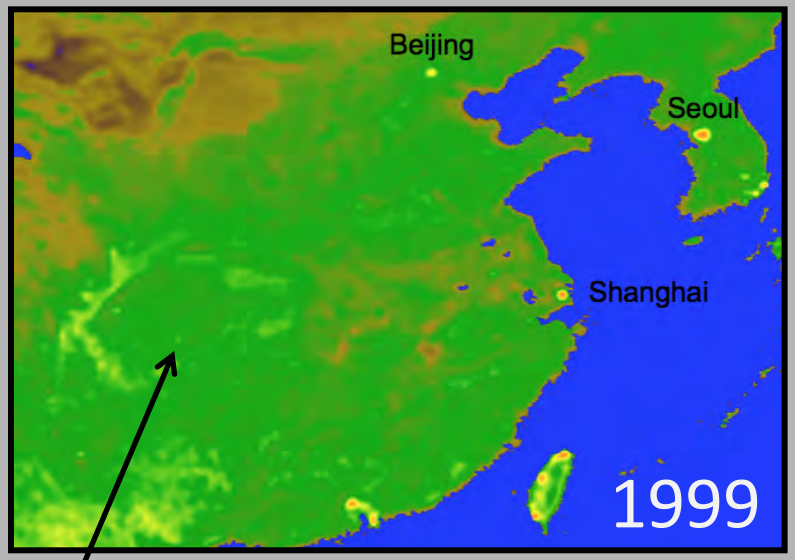
1. energy and resource use, etc.
2. urban heat islands.

Mean July-Sept. SeaWinds Ku-band microwave backscatter in 1999 & 2009

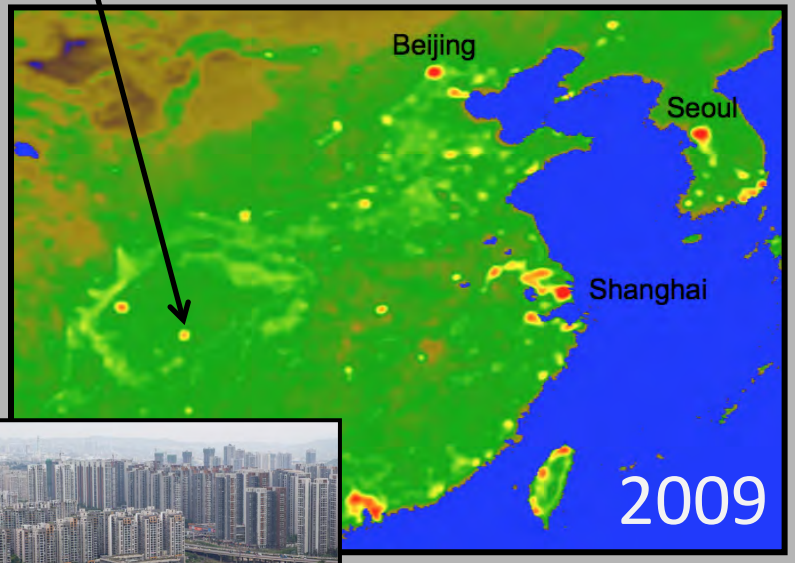


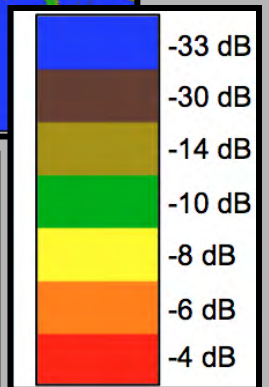
Mexico City





Chongqing



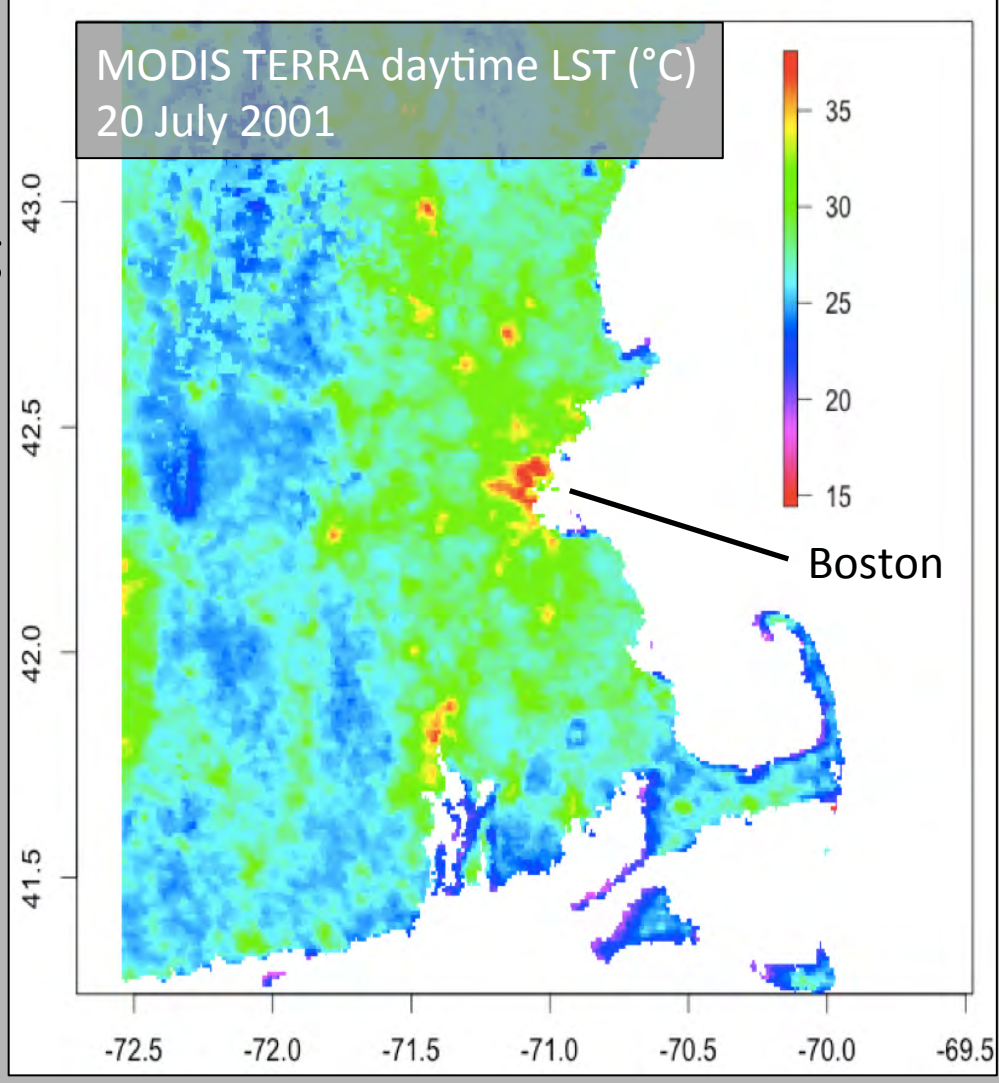


quev data
http://scp.byu.edu

Urban heat islands

Causes – Daytime:
energy balance driven by incoming solar radiation; land surface **albedo** and capacity to **evaporate** water (land cover).

Causes – Nighttime:
cooling often inhibited by **thermal inertia of built environment** and **waste heat exhaust** from energy use.



Mortality risk in US cities increased by ~2.5% per °F during prolonged periods of extreme heat (Anderson & Bell 2011).

Lack of nocturnal cooling can critically affect the amount of heat stress in large city core regions (Changnon et al. 1996).

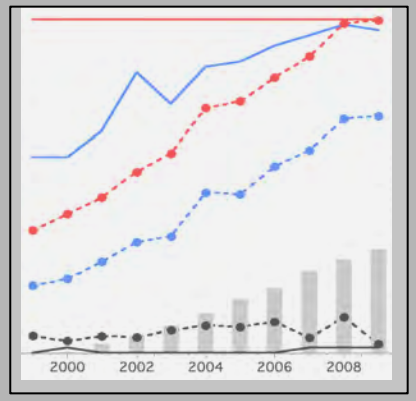
Project Overview

MODIS: map global urban expansion 2000-2010

MODIS: Land Surface Temperature
- Daytime and Nighttime LSTs
- Urban-Rural LST differences

Global Annual Urban Metrics
- **MODIS**: urban extent
- **SeaWinds**: urban backscatter
- **DMSP/OLS**: nighttime lights
- **MODIS**: % vegetation cover
- **MODIS**: EVI
- **MODIS**: rural landcover

Temporal trends



Empirical Analyses:
- stepwise multiple regression;
- classification & regression tree

Spatial patterns

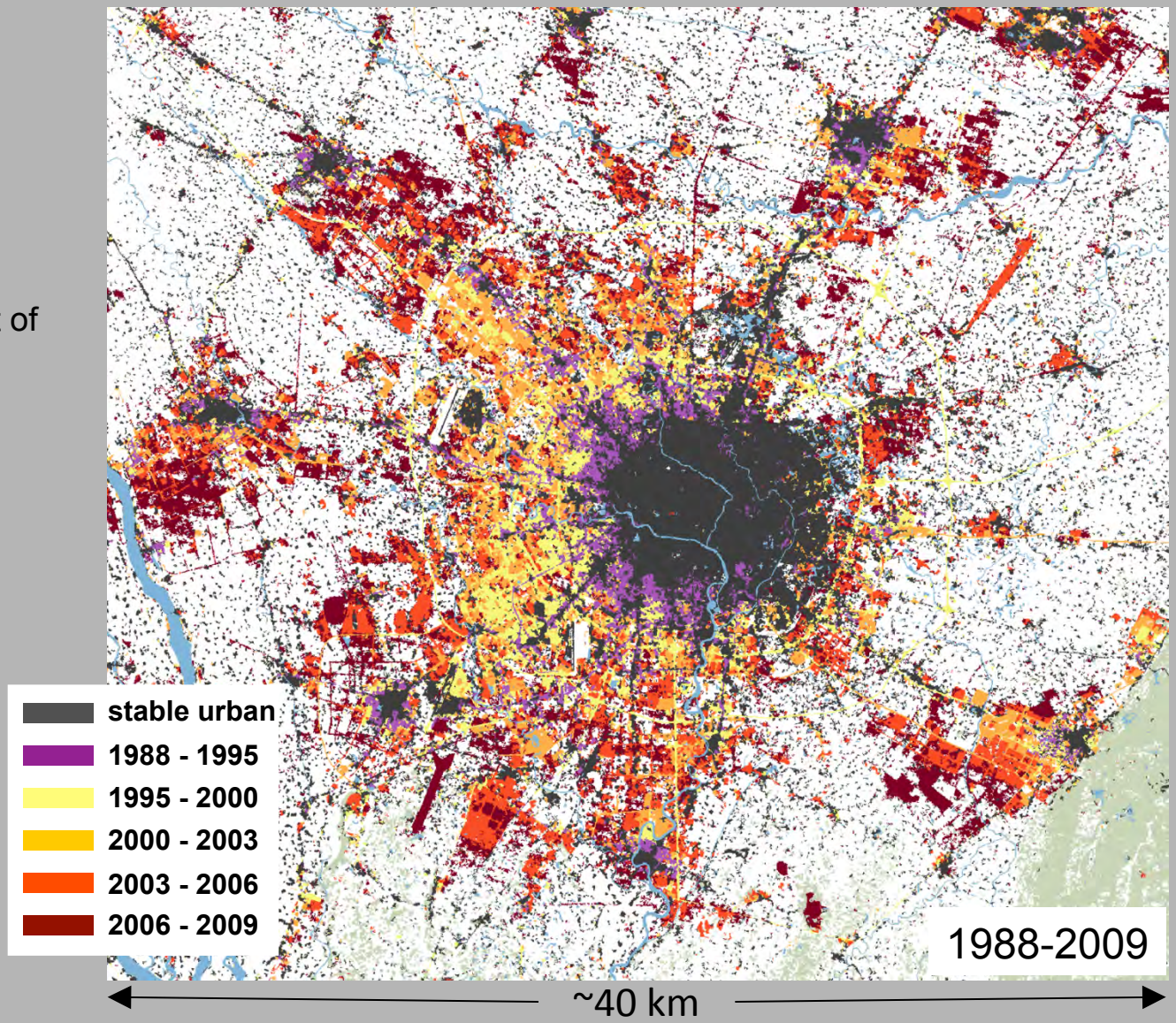
Explanatory power for daytime and nighttime urban heat islands for each urban metric, with confidence intervals.

Mapping urban growth – an example for one city

from Annemarie Schneider

Previous work in China and Southeast Asia

- Change detection using Landsat satellite data
- Assess trajectory of multiple time points
- Multitemporal data is key, but requires large amount of data processing
- Rely instead on coarse resolution datasets (250m–1km)



Chengdu, Western China:
400% increase
in urban land, 1988-2009

Methods for mapping global urban expansion

Step 1: Delineate study area extent

- Merge 2001 MODIS map of urban extent with all point datasets on cities (GRUMP, UN, etc.).
- Categorize urban patches into three classes based on areal extent and population.
- Buffer by small, medium, and large urban areas by 5, 25, and 100 km, respectively.

Study extent (white) represents 30% of total land area in the region

Schneider et al. 2015 *ERL*
Mertes et al. 2015 *RSE*

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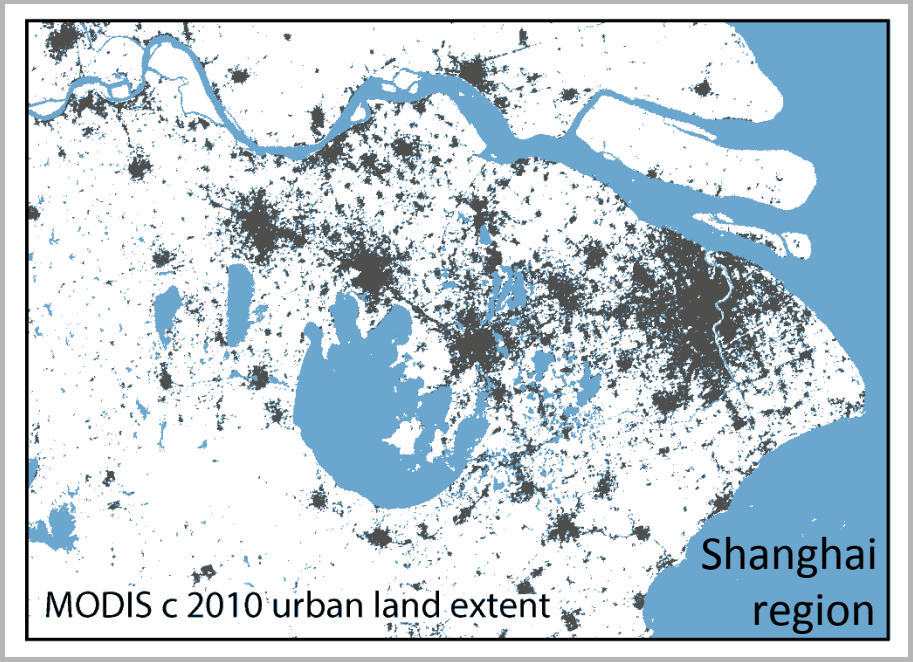
Step 2: Map c. 2010 urban extent

- Supervised decision tree classification of 500-m multispectral data — probability of urban extent.
- Prior probability surface of urban land — 250-m vegetation index data.
- Combine probabilities using data fusion (Bayes' Rule).

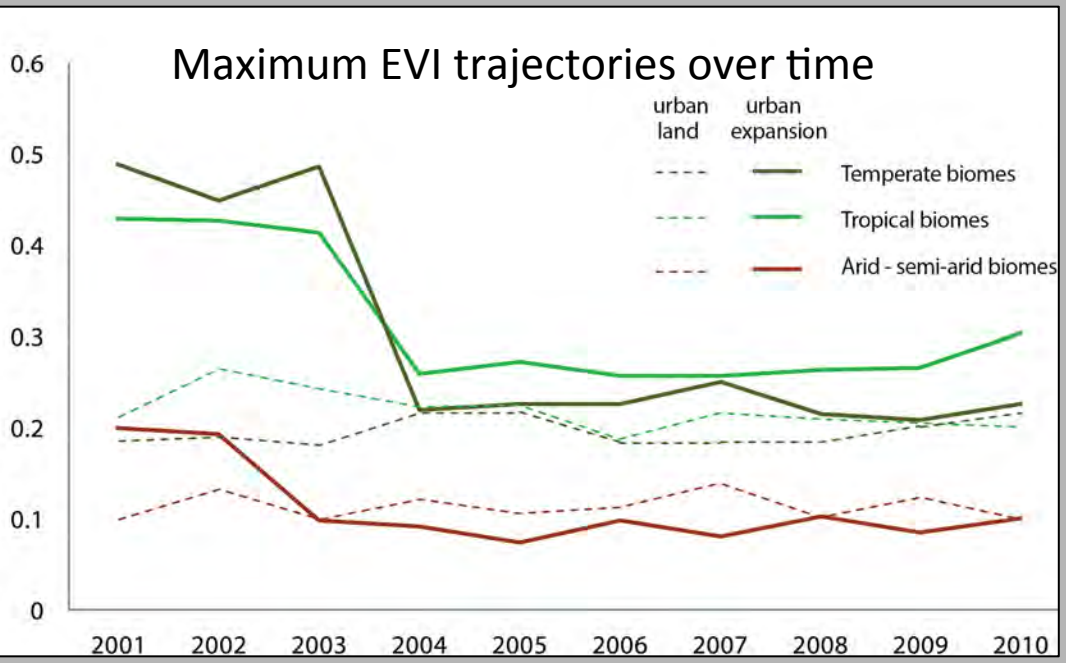
Schneider et al. 2015 *ERL*
Mertes et al. 2015 *RSE*

Step 3: urban expansion



Change detection

- Work backwards: were 2010 urban areas urban in 2000, or did they urbanize between 2000 and 2010?
- Use 2010 urban map to constrain change detection.
- 10-y growing season max EVI data; stacked, multi-date composite.



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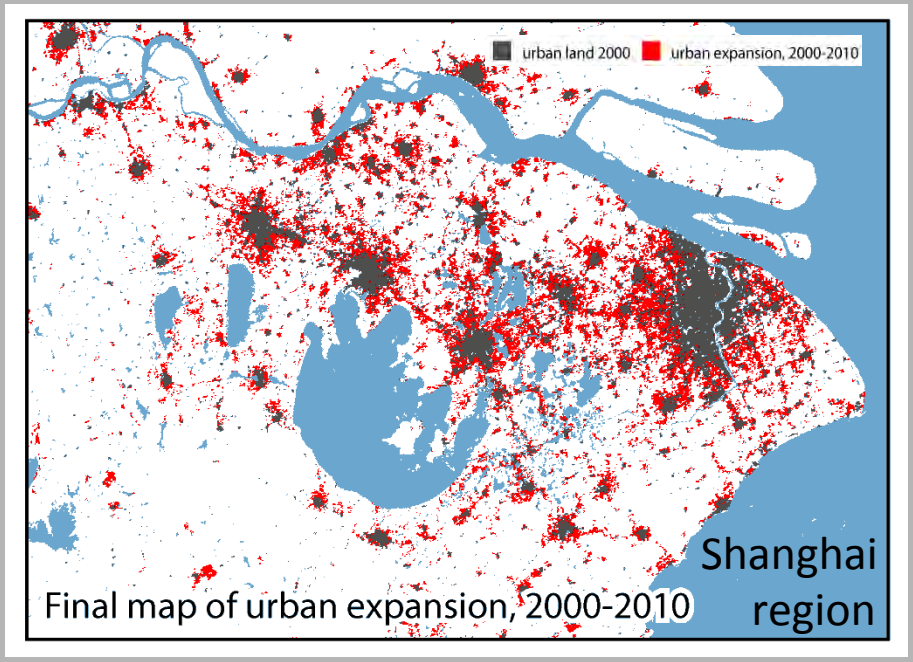

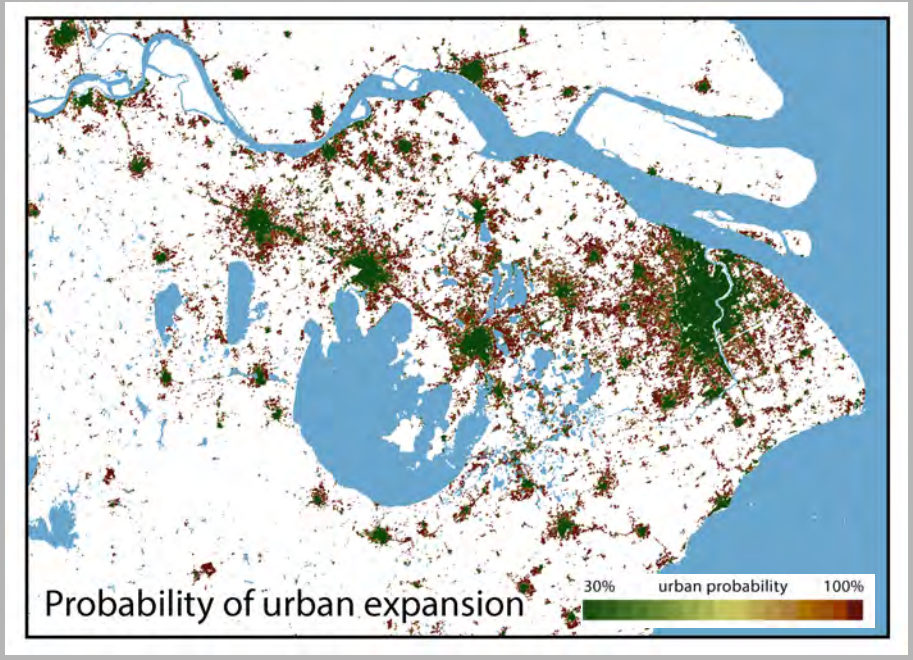

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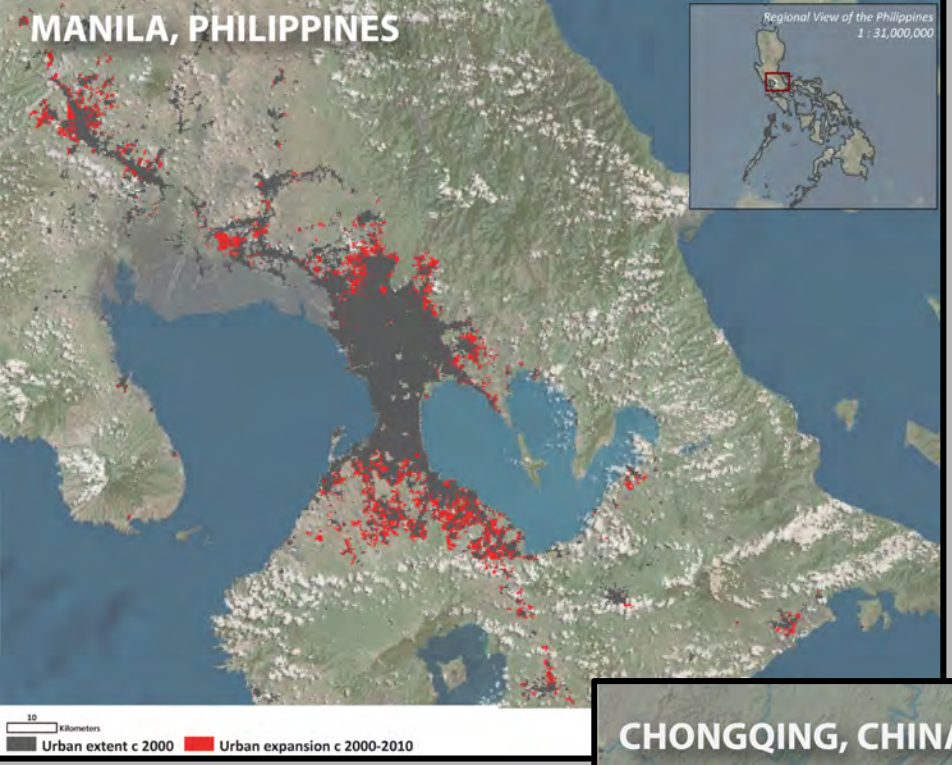
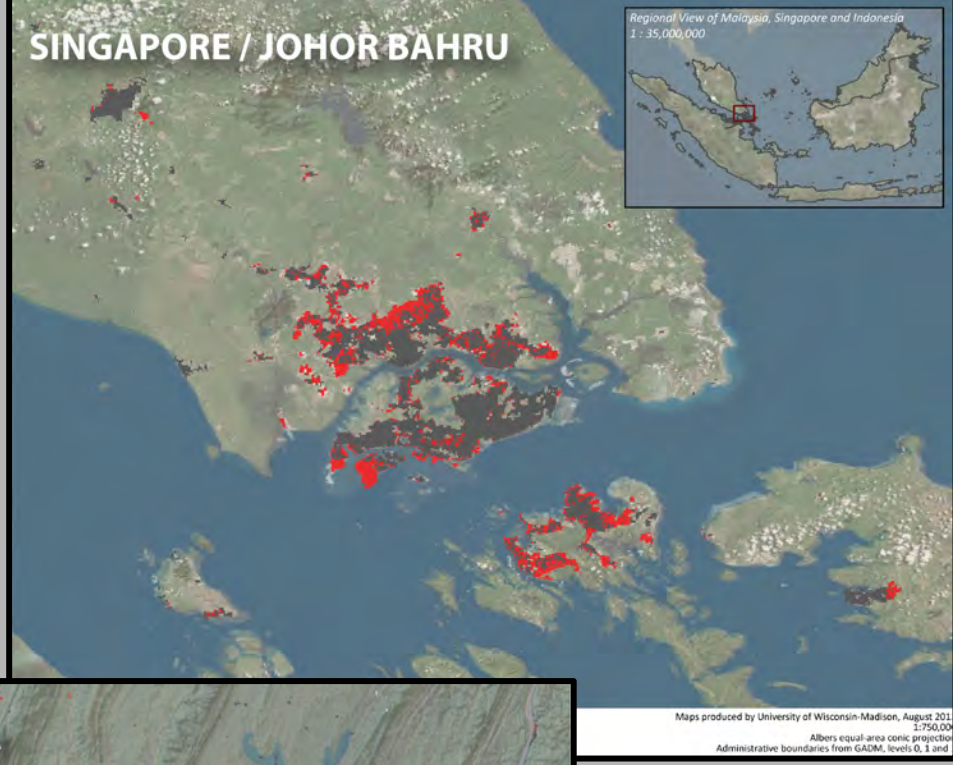
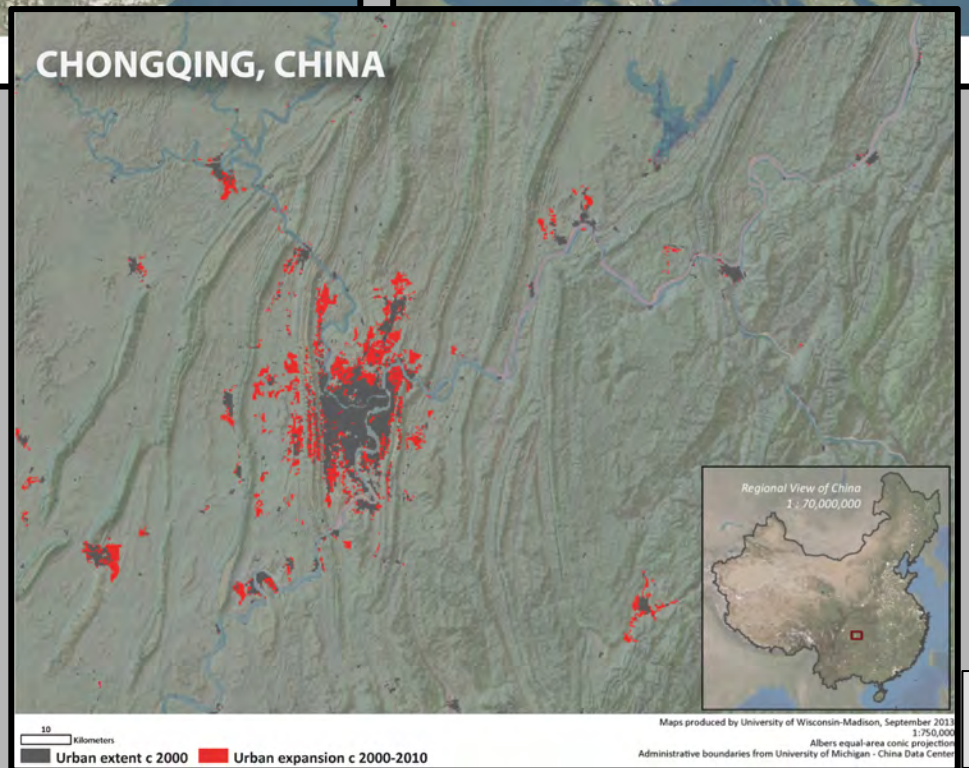
- Work backwards: were 2010 urban areas urban in 2000, or did they urbanize between 2000 and 2010?
- Use 2010 urban map to constrain change detection.
- 10-y growing season max EVI data; stacked, multi-date composite.
- Supervised boosted decision tree algorithm (C4.5).
- Local training data revisited, urban sites labeled as *(1) stable urban areas*, or *(2) areas urbanized, 2000-2010.*
- Output probabilities iteratively thresholded, compared to c2010 Google Earth imagery.

Schneider et al. 2015 *ERL*
Mertes et al. 2015 *RSE*







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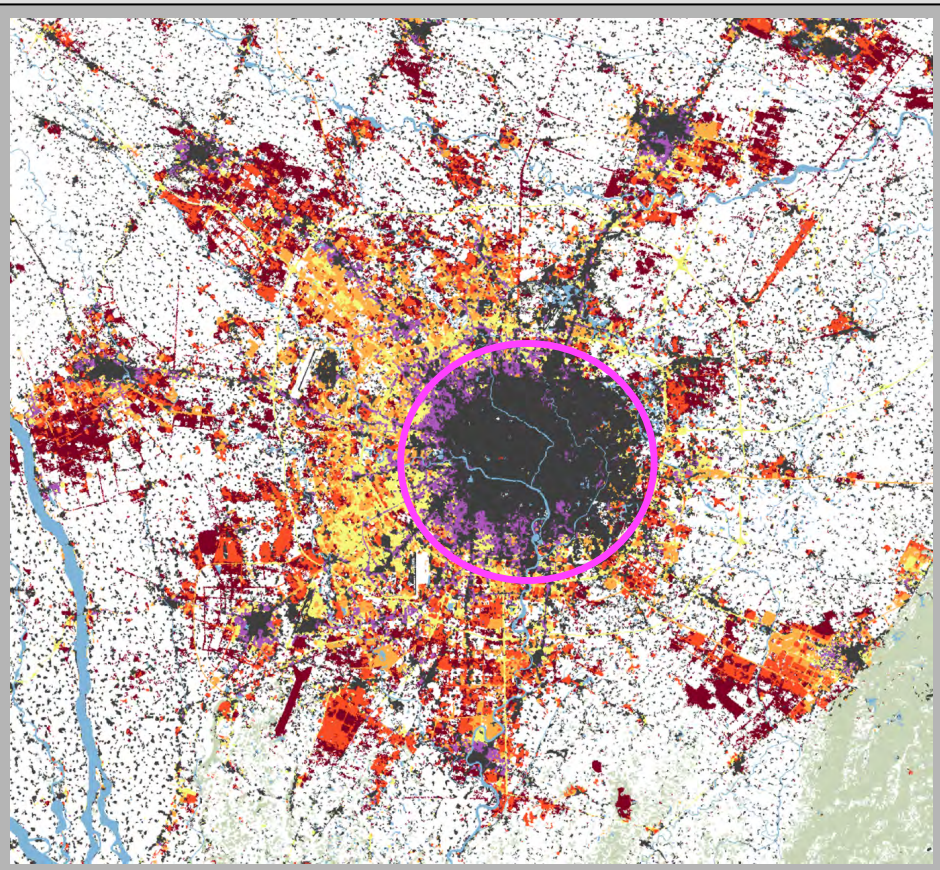
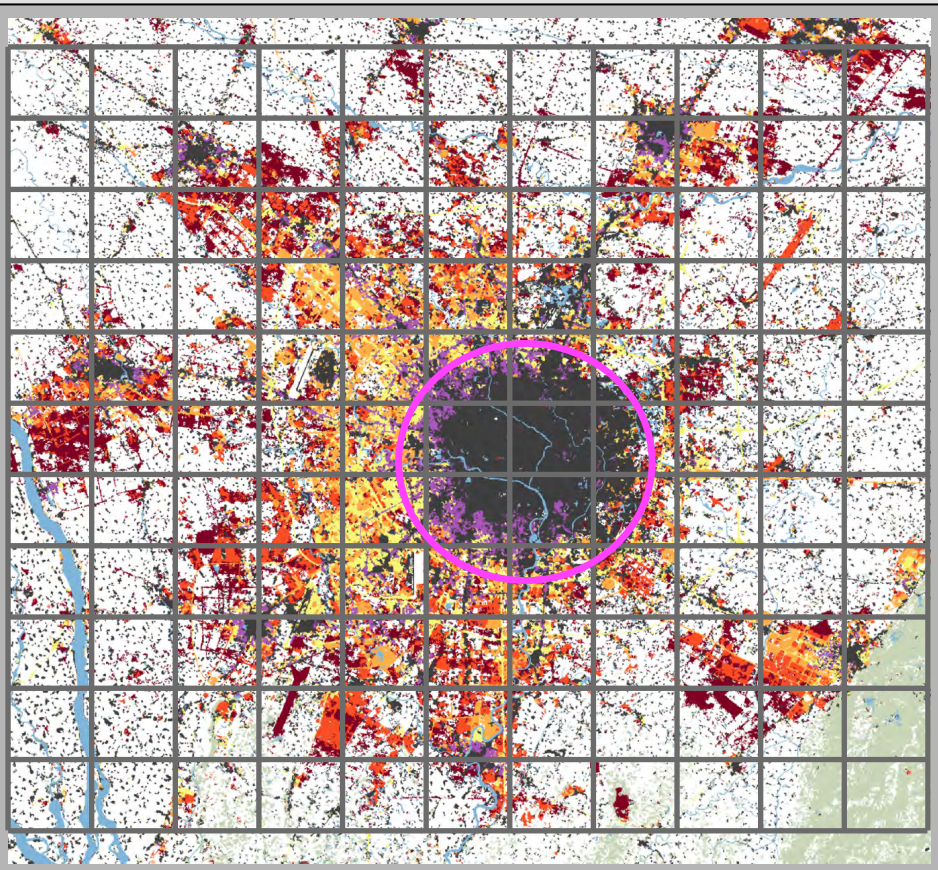
Chengdu –was the urban core ‘stable urban’?



~40 km

stable urban
1988 - 1995
1995 - 2000
2000 - 2003
2003 - 2006
2006 - 2009

Chengdu – the urban core got 'brighter', both nighttime lights and backscatter



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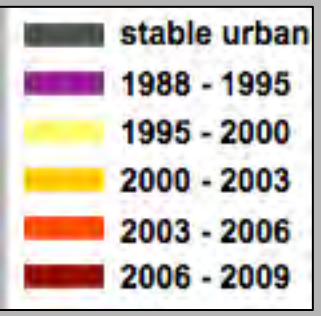
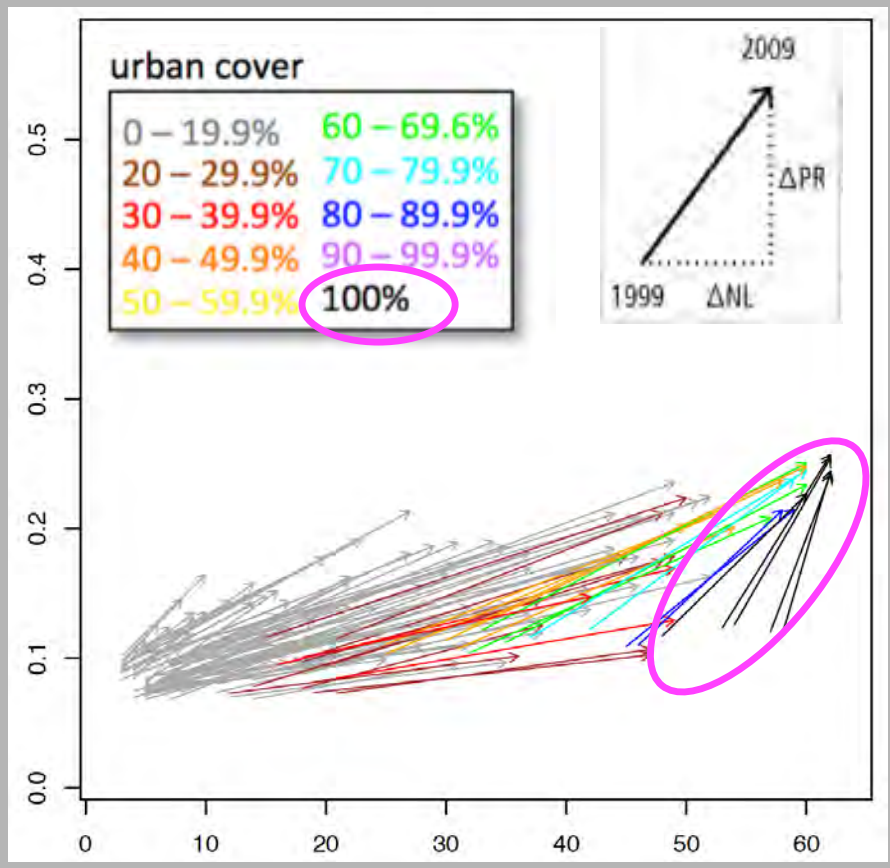


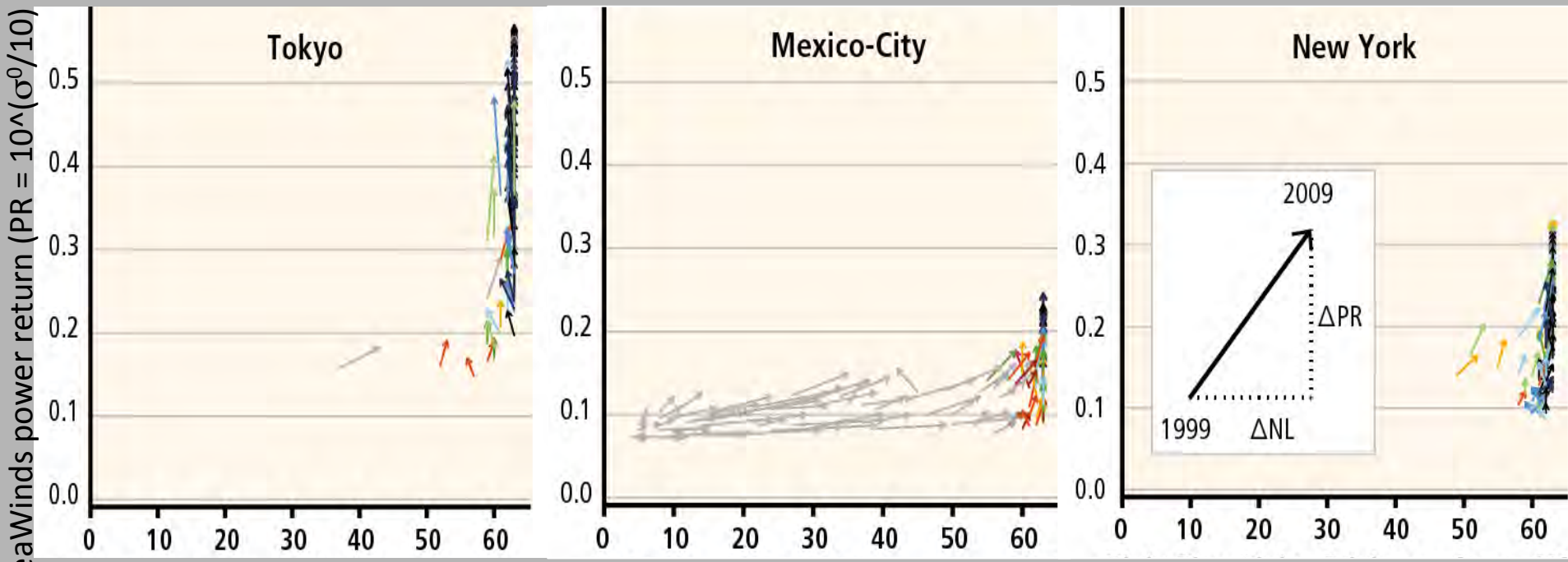


DMSP/OLS night time lights (NL; max. = 63)

- 11 x 11 grid (0.05°) centered on Chengdu (approx. 40x50 km)
- summer mean backscatter; annual mean night time lights.
- arrows point from NL and PR in 1999 to NL and PR in 2009.
- urban fraction (arrow color) from MODIS land cover product.

Frolking et al. 2013 *ERL*

1999-2009 change in night time lights and microwave backscatter



- 11 x 11 grid (0.05°) centered on each city (approx. 50x50 km)
- summer mean backscatter; annual mean night time lights.
- arrows point from NL and PR in 1999 to NL and PR in 2009.
- urban fraction (arrow color) from MODIS land cover product.
- water grid cells masked out.

urban cover

0 – 19.9%	60 – 69.6%
20 – 29.9%	70 – 79.9%
30 – 39.9%	80 – 89.9%
40 – 49.9%	90 – 99.9%
50 – 59.9%	100%

Frolking et al. 2013 *ERL*

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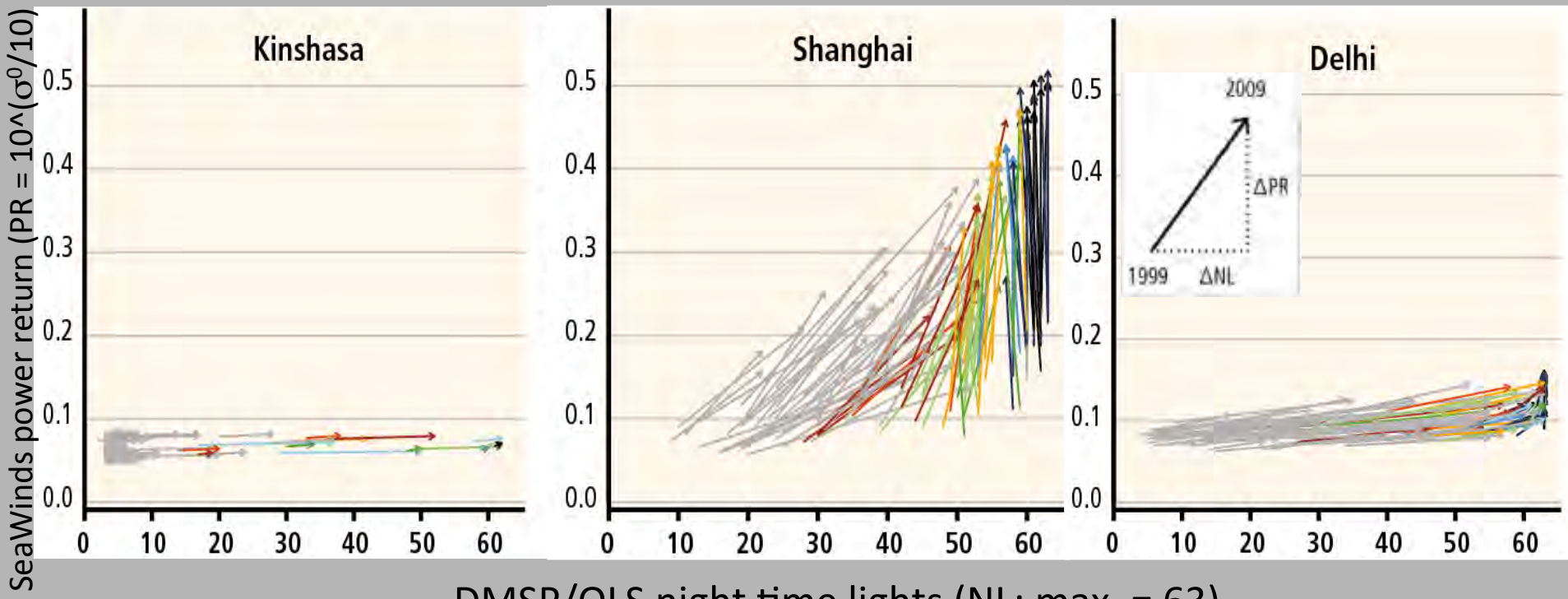

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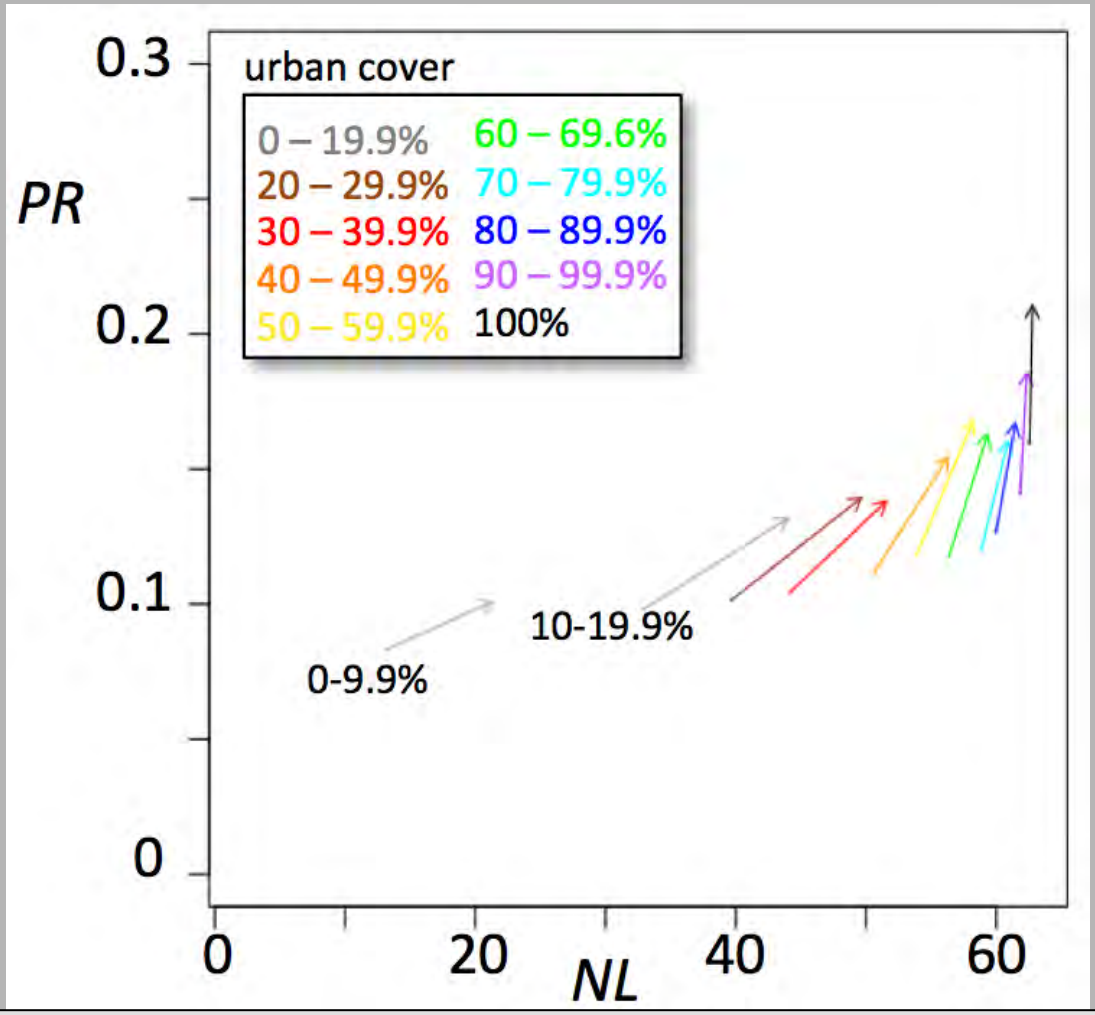
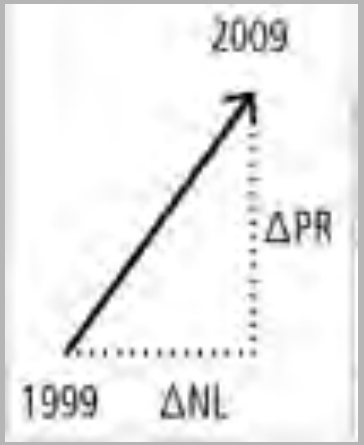


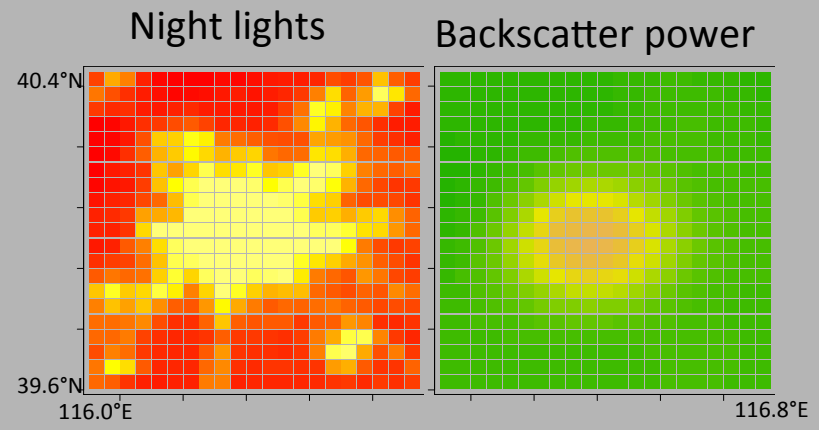


Mean of 121 grid cells (0.05°) for 100 large cities, disaggregated by percent urban cover.

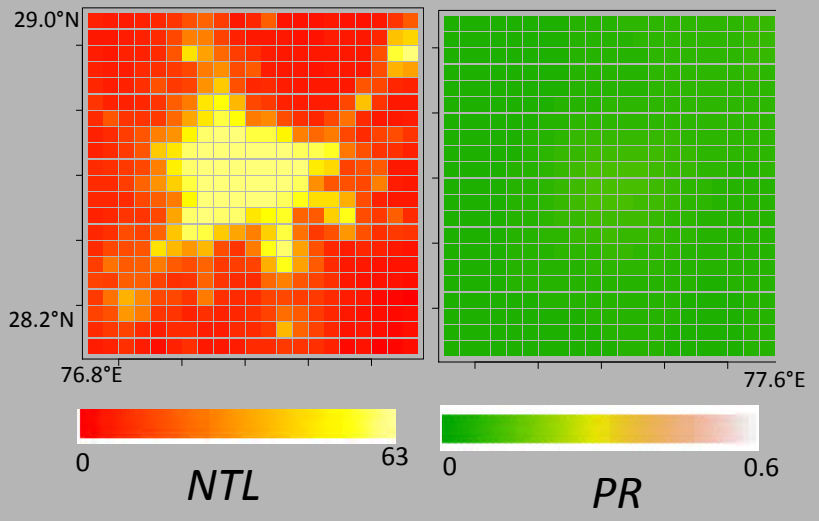
Frolking et al. 2013 *ERL*

Night lights & backscatter – different urban characteristics.

2009



Beijing



Delhi

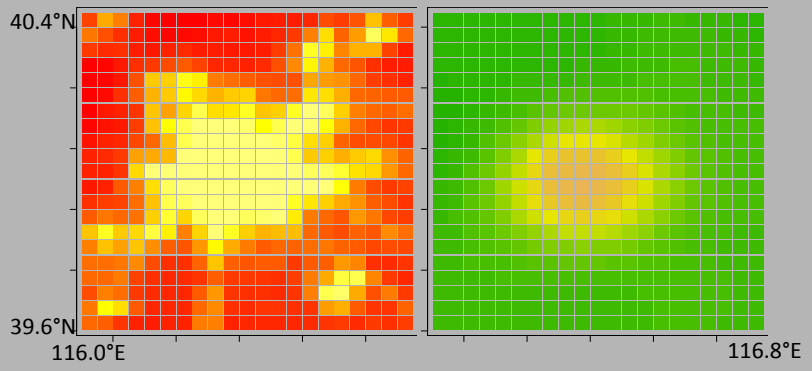
Plan view: 21x21 grid cells (0.05°)

Night lights & backscatter – different urban characteristics & modes of change.

2009

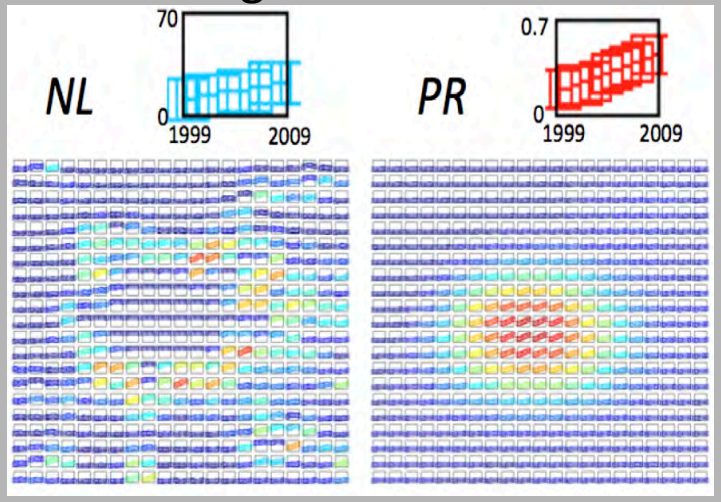
Night lights

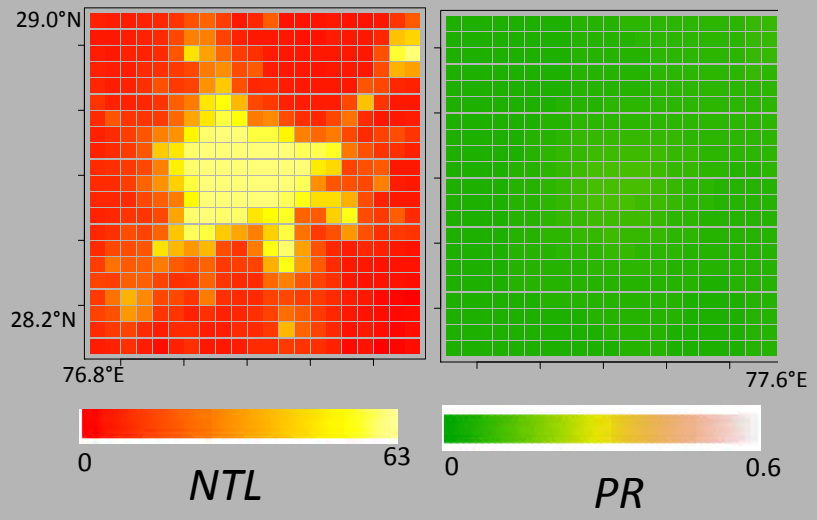
Backscatter power



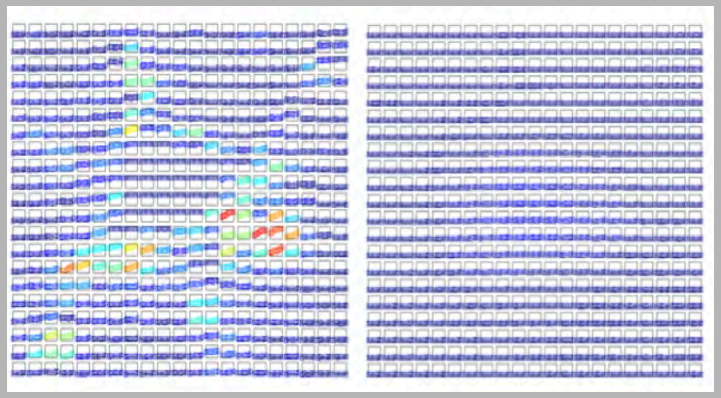
Beijing

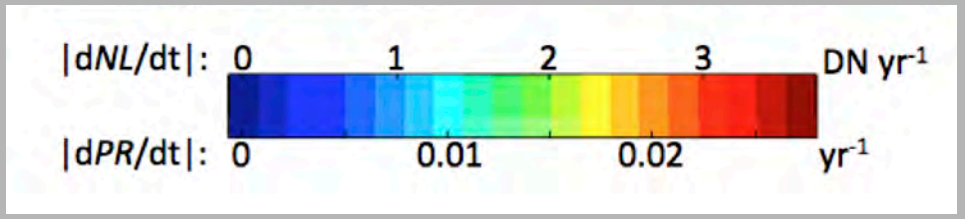
Change 1999 – 2009





Delhi





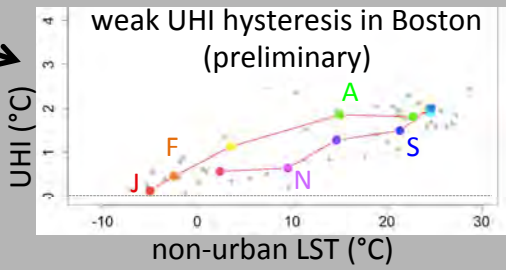
Plan view: 21x21 grid cells (0.05°)

Still to do:

The proposed urban heat island analyses. Specific questions we plan to address:

1. Comparing eastern Asia with eastern North America, are there differing trends in UHI that can be associated with different rates and types of 2000-2010 urban growth – lateral expansion, night lights, and/or backscatter?

2. What does UHI seasonal hysteresis spatial variability, as reported by Zhou et al. (2013, *GRL*), correlate with?



3. Do we see a relationship between UHI and urban 'roughness', as simulated by Zhao et al. (2014, *Nature*), using backscatter as remote sensing metric of 'roughness'?

Thank you

EXTRA SLIDES

Step 4: accuracy assessment

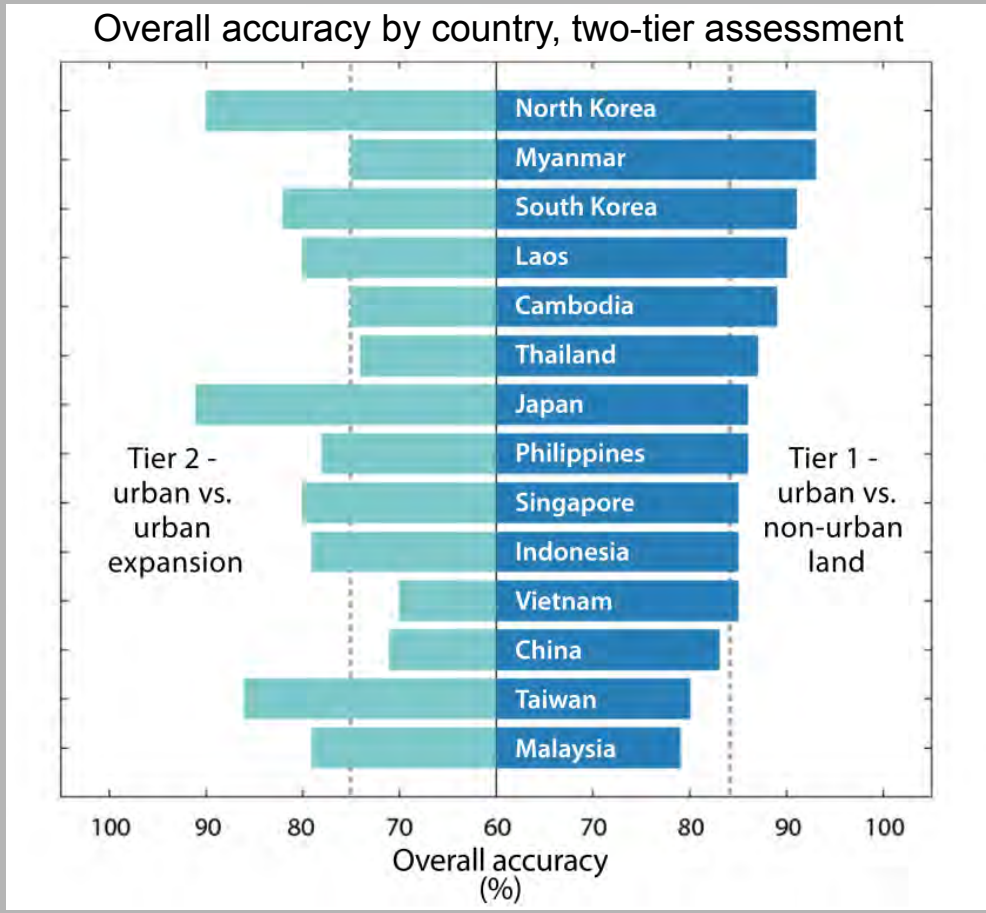
Assessing map accuracy

- Maps assessed using two-tier approach

  Tier 1: assess c2010 urban extent

  Tier 2: assess maps of urban expansion

- Approach: stratified random sample of sites labeled by multiple analysts, double-blind procedure.



- Results for overall accuracy, country-level:

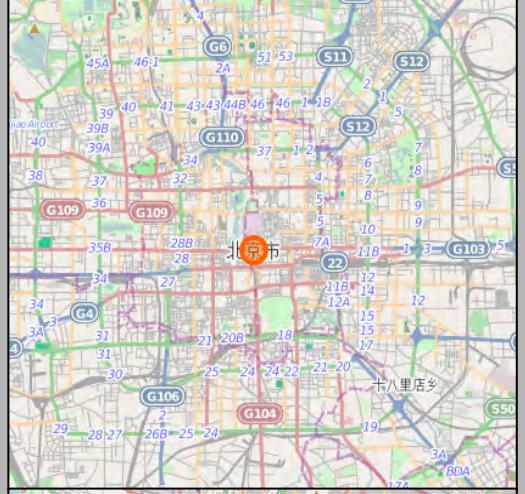
  Tier 1 (extent): 79-93% (*mostly commission errors – overestimating urban*)

  Tier 2 (expansion): 70-91% (*mostly commission errors – overestimating expansion*)

- errors propagate – start with a good classification!

Quikscat level 1b backscatter

www.OpenStreetMap.org



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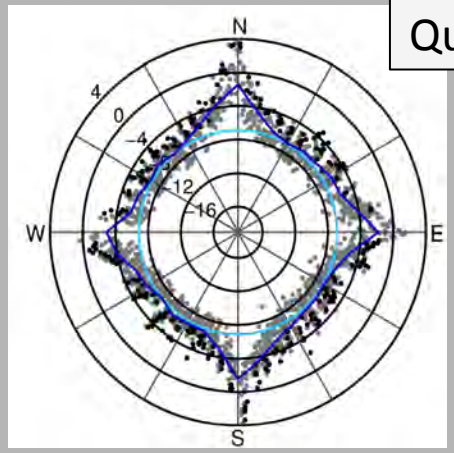
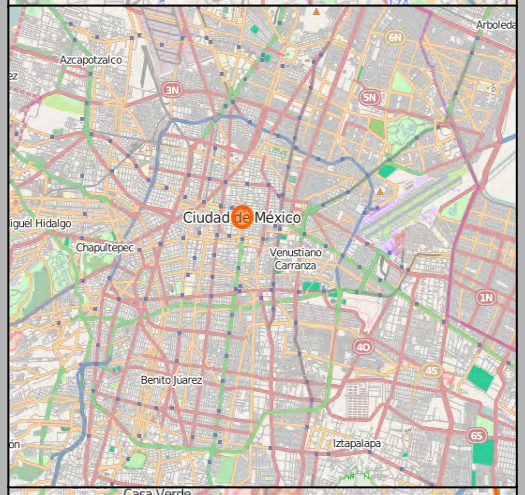
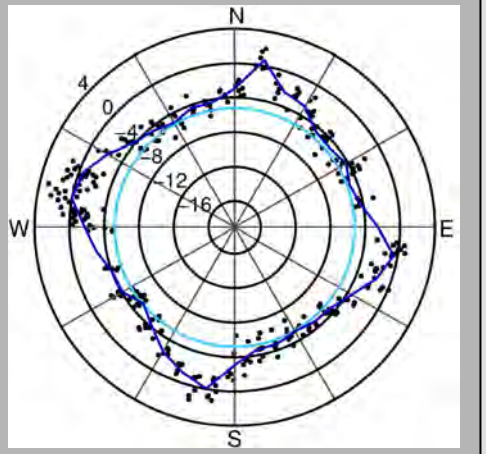
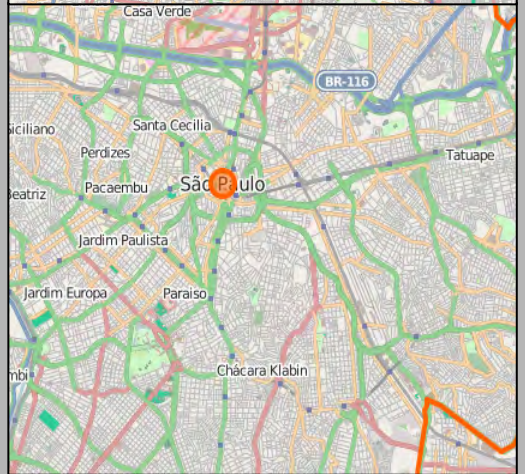


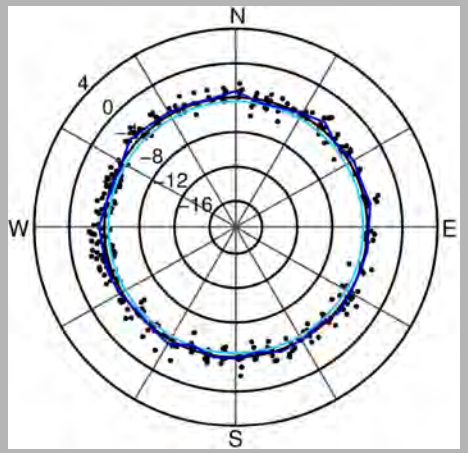


Mexico City



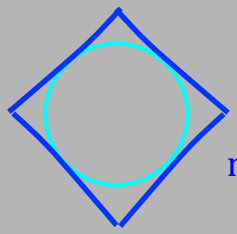


São Paulo



Azimuthal dependence of individual backscatter returns vary by city (high to none). Averaging over one or more months fully samples azimuthal range.

Although urban backscatter magnitude changed over 1999-2009, there was no trend in azimuthal dependence for several large cities we sampled.

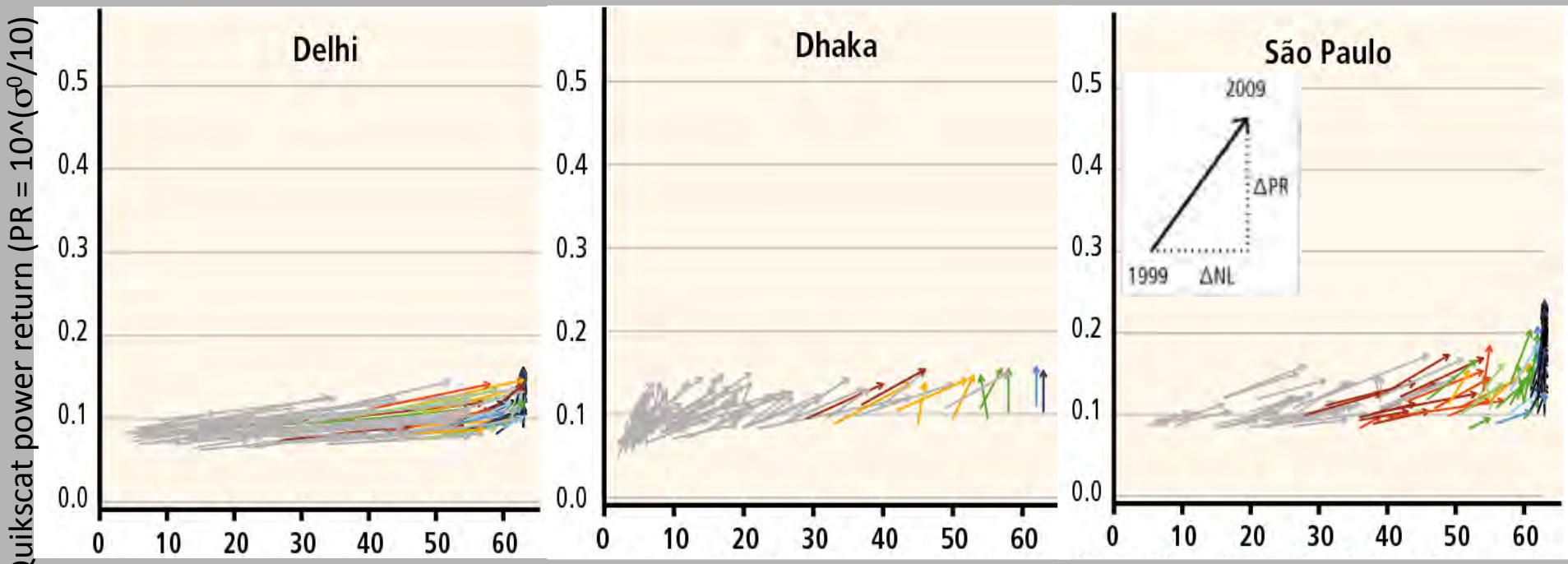


floor

mean by angle

Paget et al. (2015)

1999-2009 change in night time lights and microwave backscatter



- 11 x 11 grid (0.05°) centered on each city.
- summer mean backscatter; annual mean night time lights.
- arrows point from NL and PR in 1999 to NL and PR in 2009.
- urban fraction (arrow color) from MODIS land cover product.
- water grid cells masked out.

urban cover

0 – 19.9%	60 – 69.6%
20 – 29.9%	70 – 79.9%
30 – 39.9%	80 – 89.9%
40 – 49.9%	90 – 99.9%
50 – 59.9%	100%