

Cities from space: new portraits of the global urban fabric

16 June 2008

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Main Questions

Why global urban maps?

Which urban map is most accurate?

How will urban expansion impact conservation?

Why global **urban**
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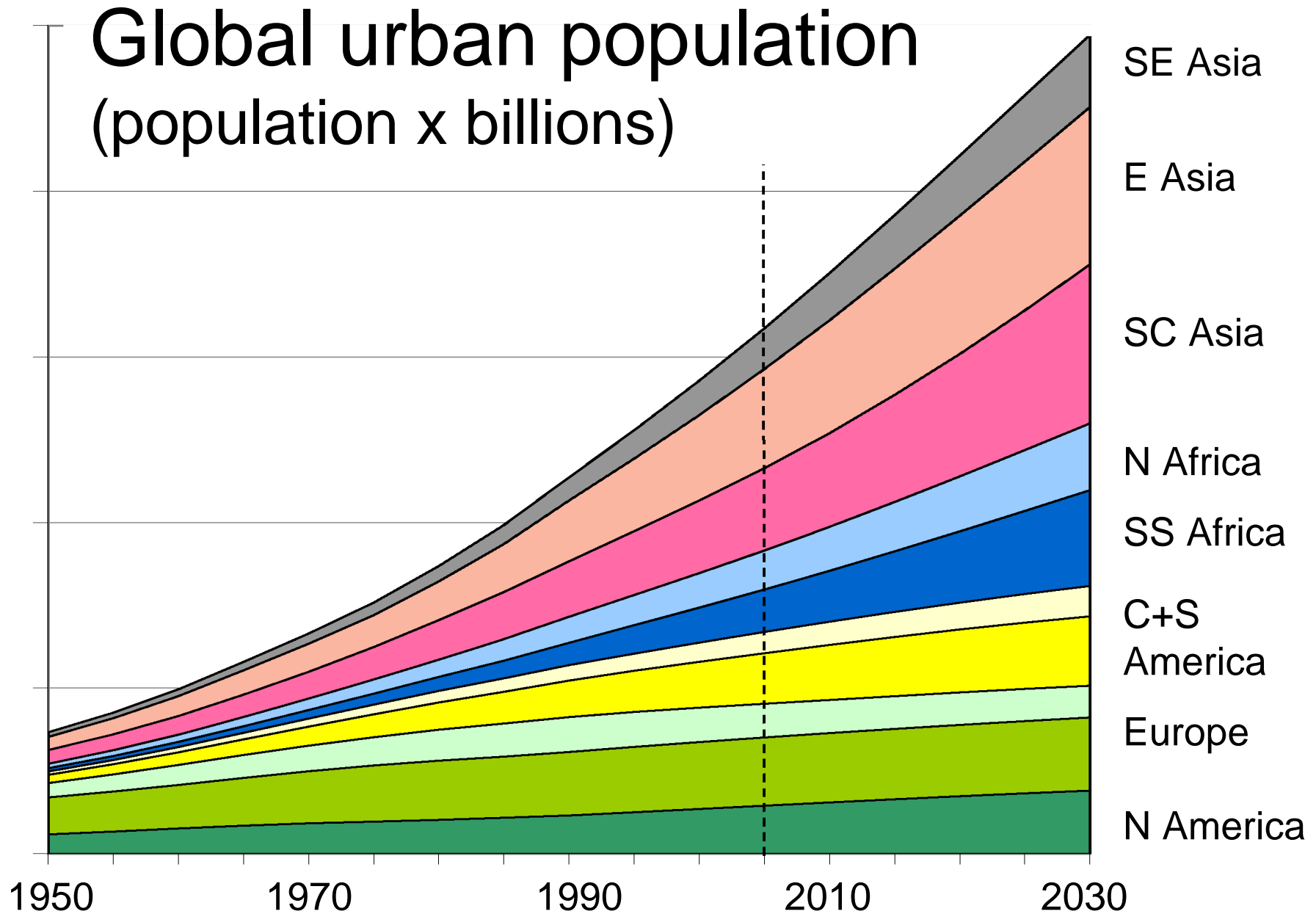
Why global urban
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Global urban population (population x billions)



Global urban area, 7 maps

(sq. km x millions)

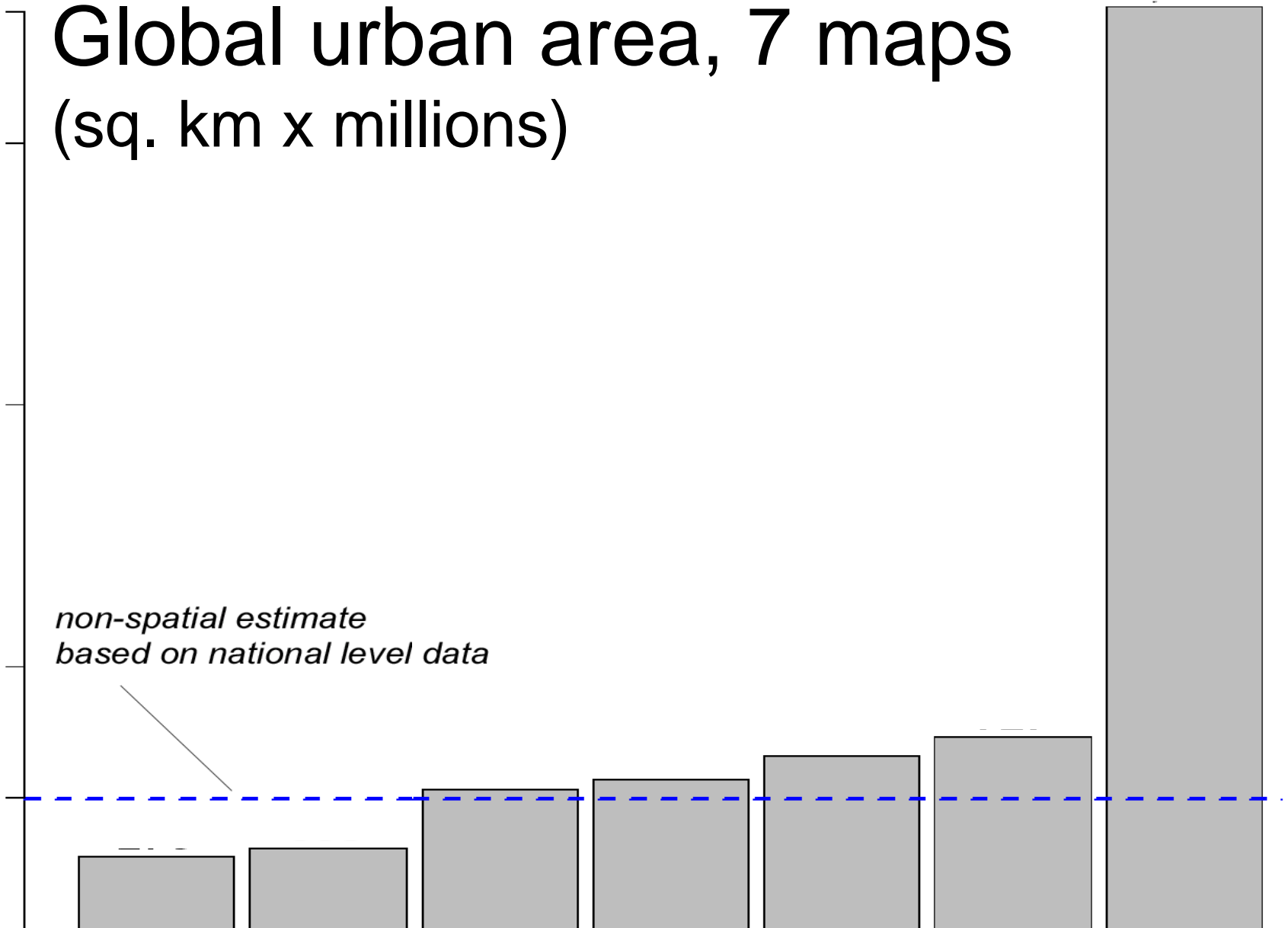
3.5

3

2

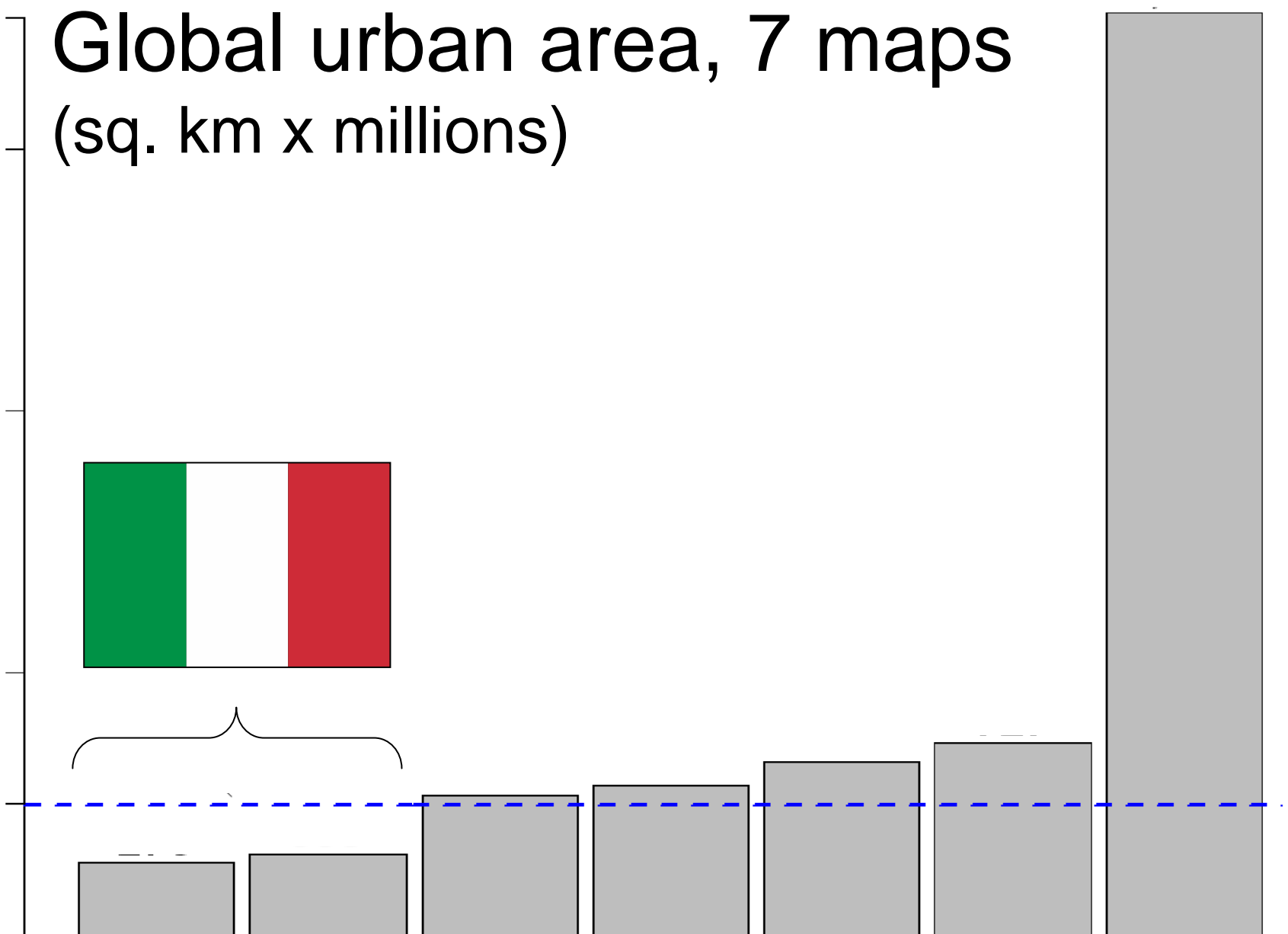
1

*non-spatial estimate
based on national level data*



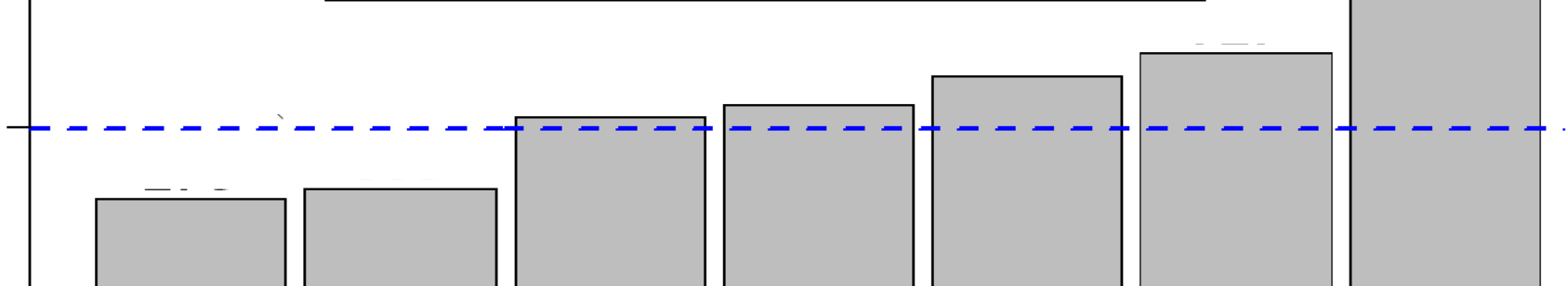
Global urban area, 7 maps

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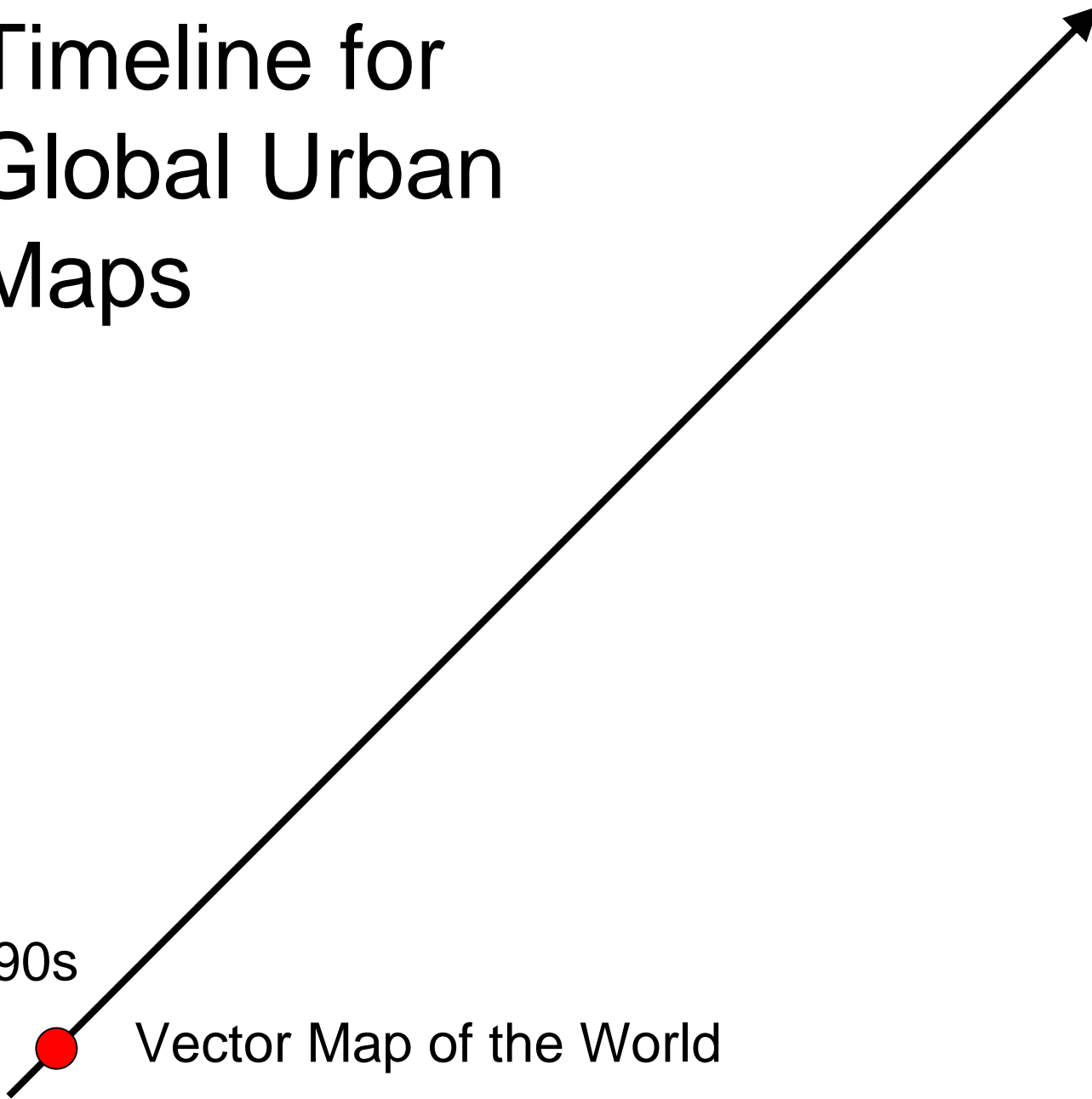
How will urban expansion impact conservation?

Timeline for Global Urban Maps

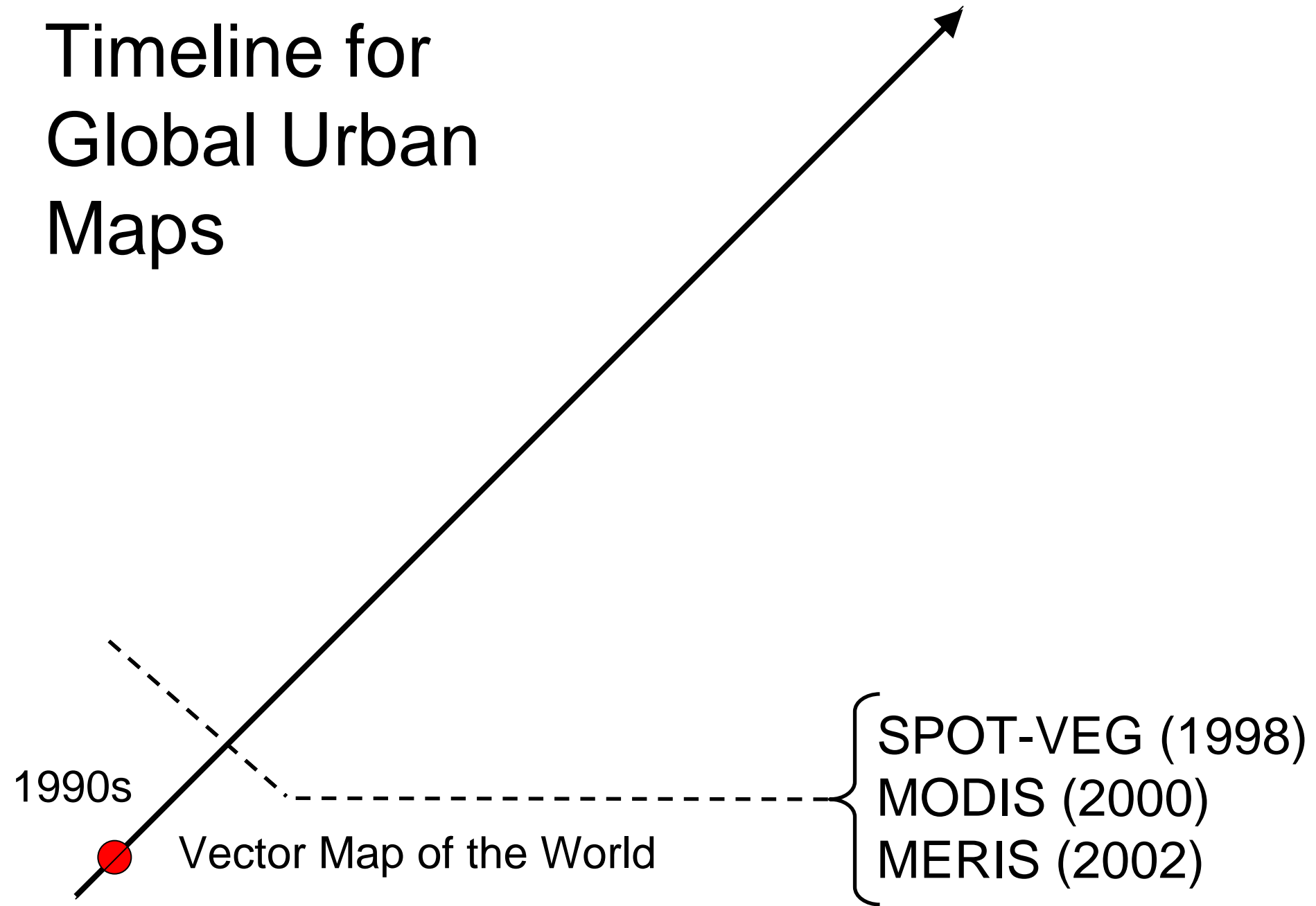
1990s



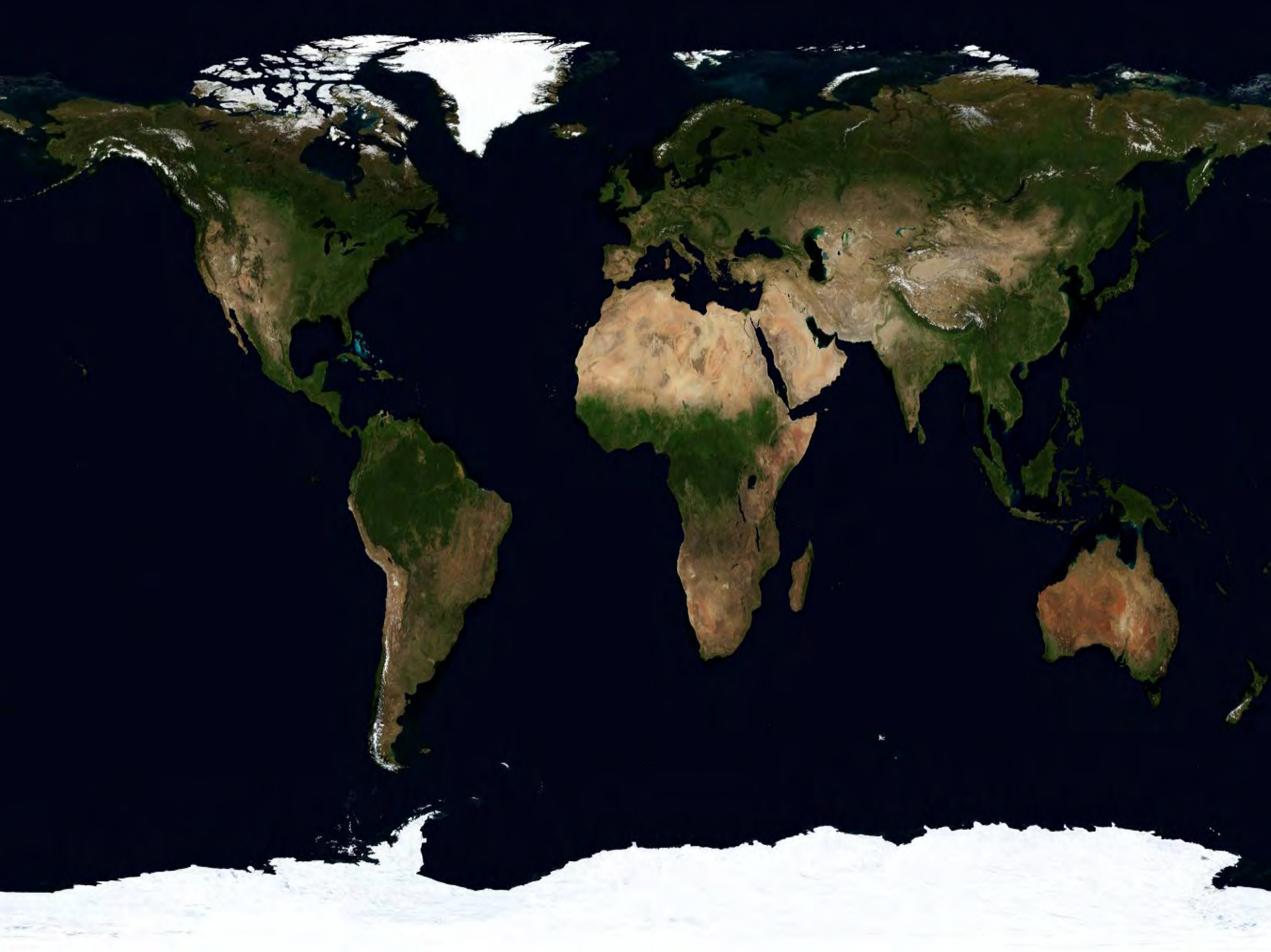
Vector Map of the World

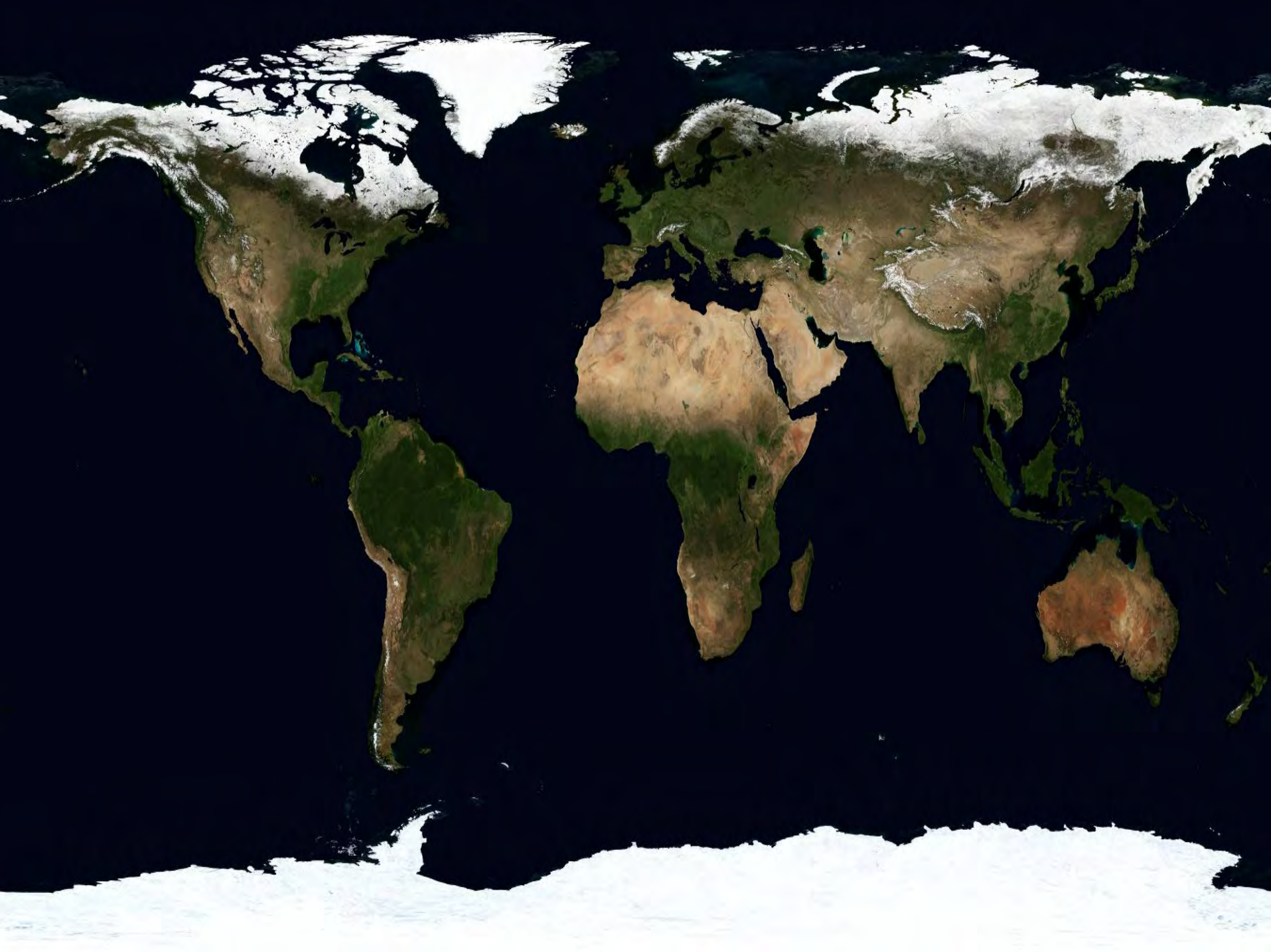


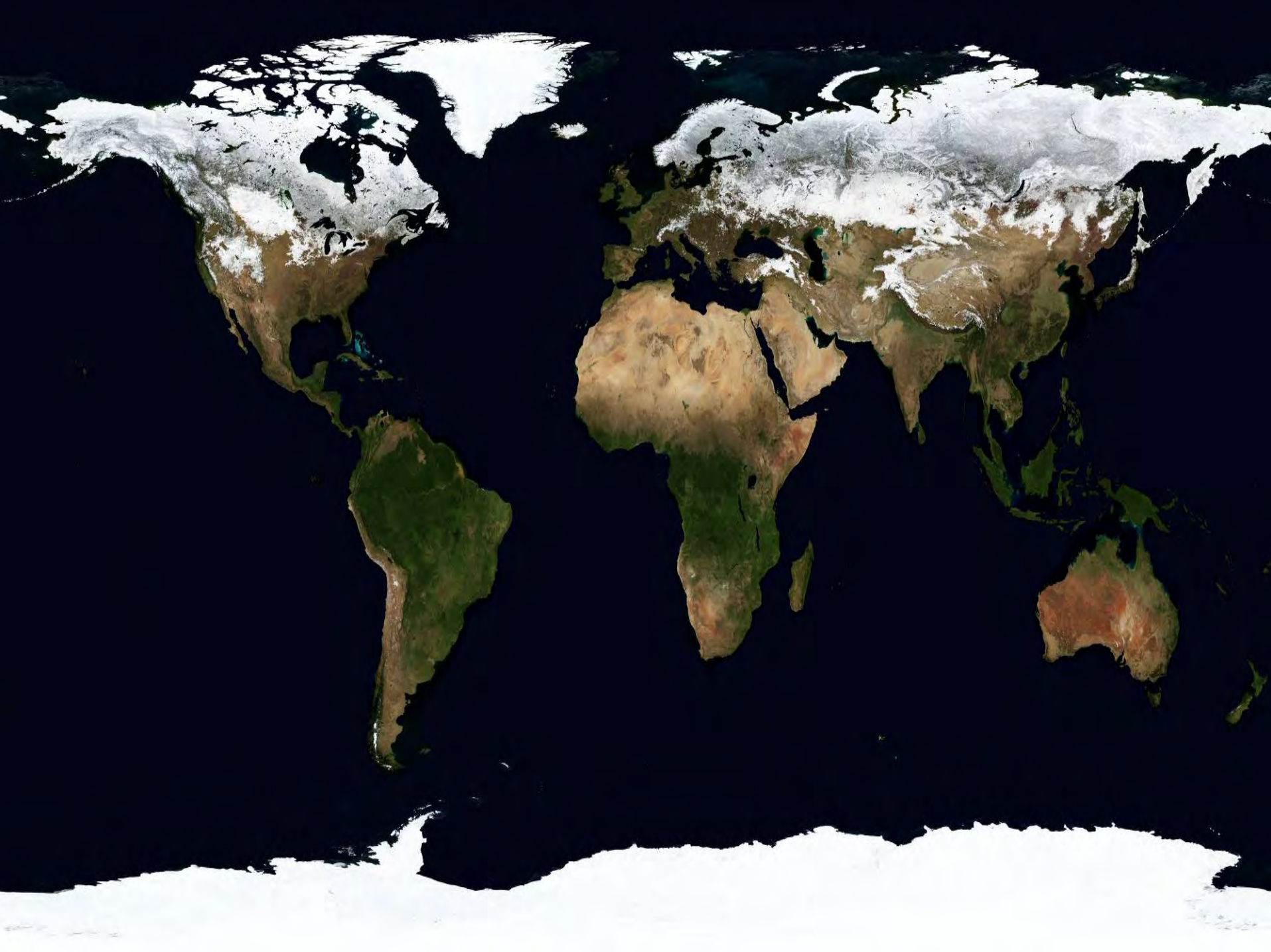
Timeline for Global Urban Maps



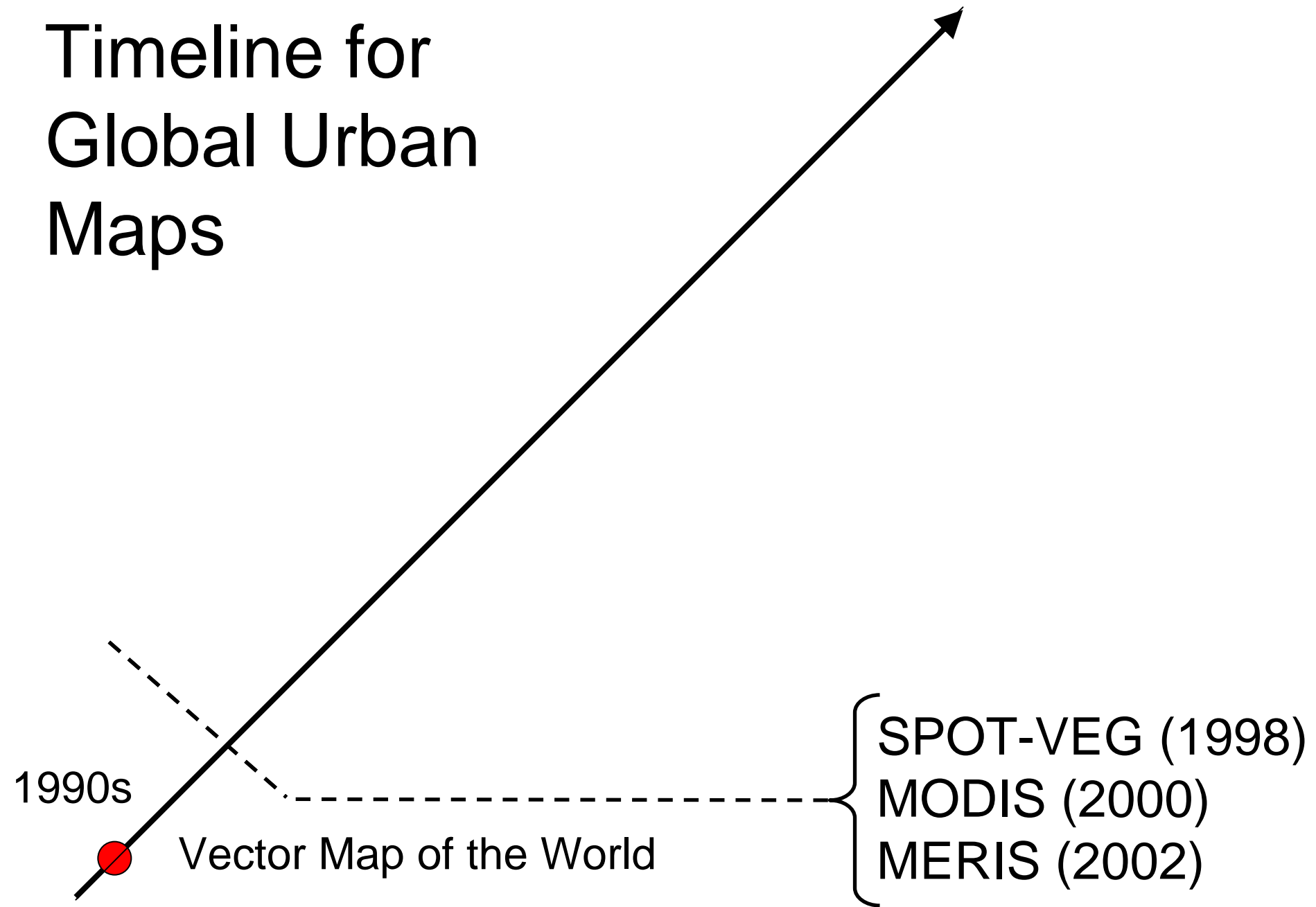




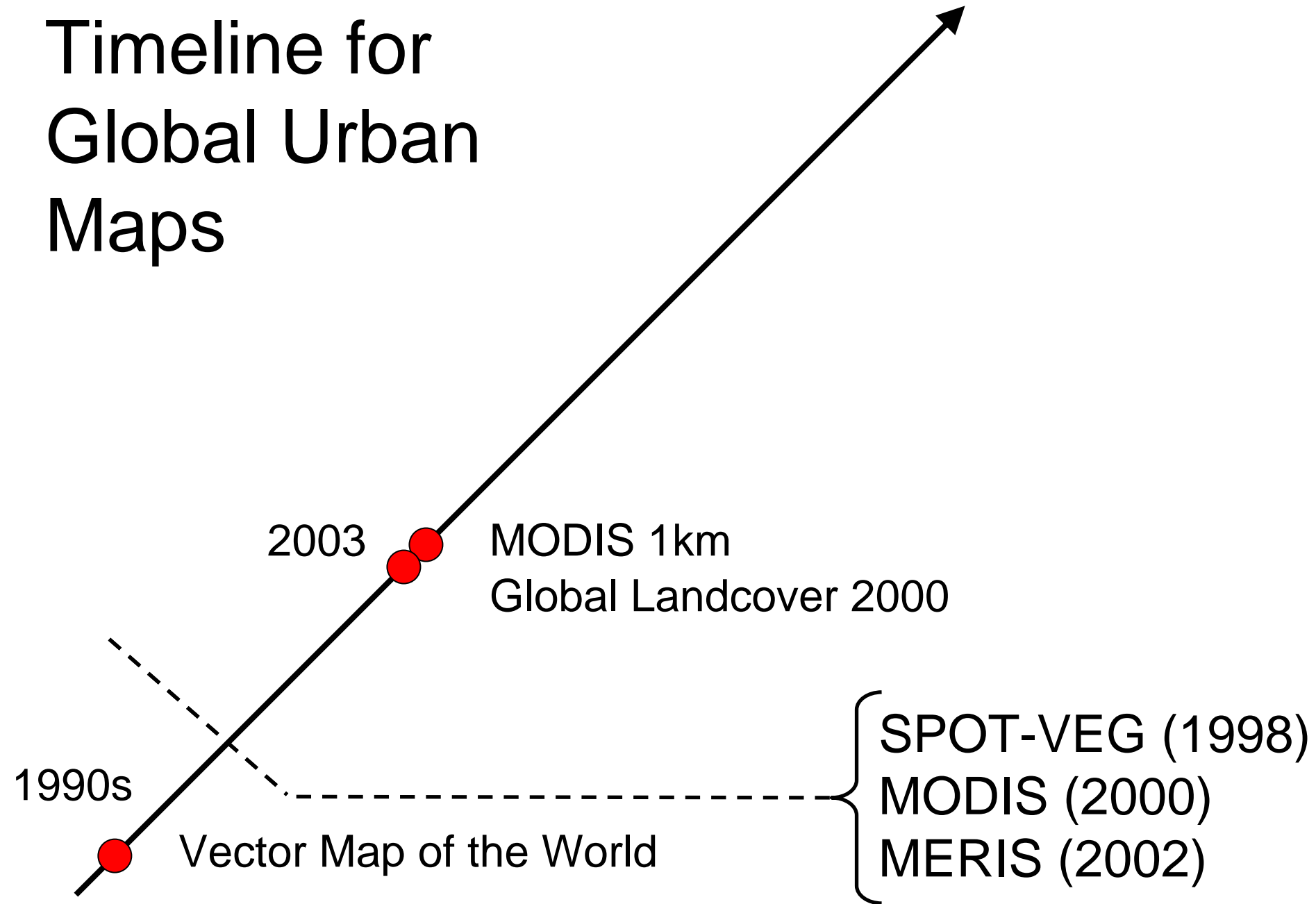


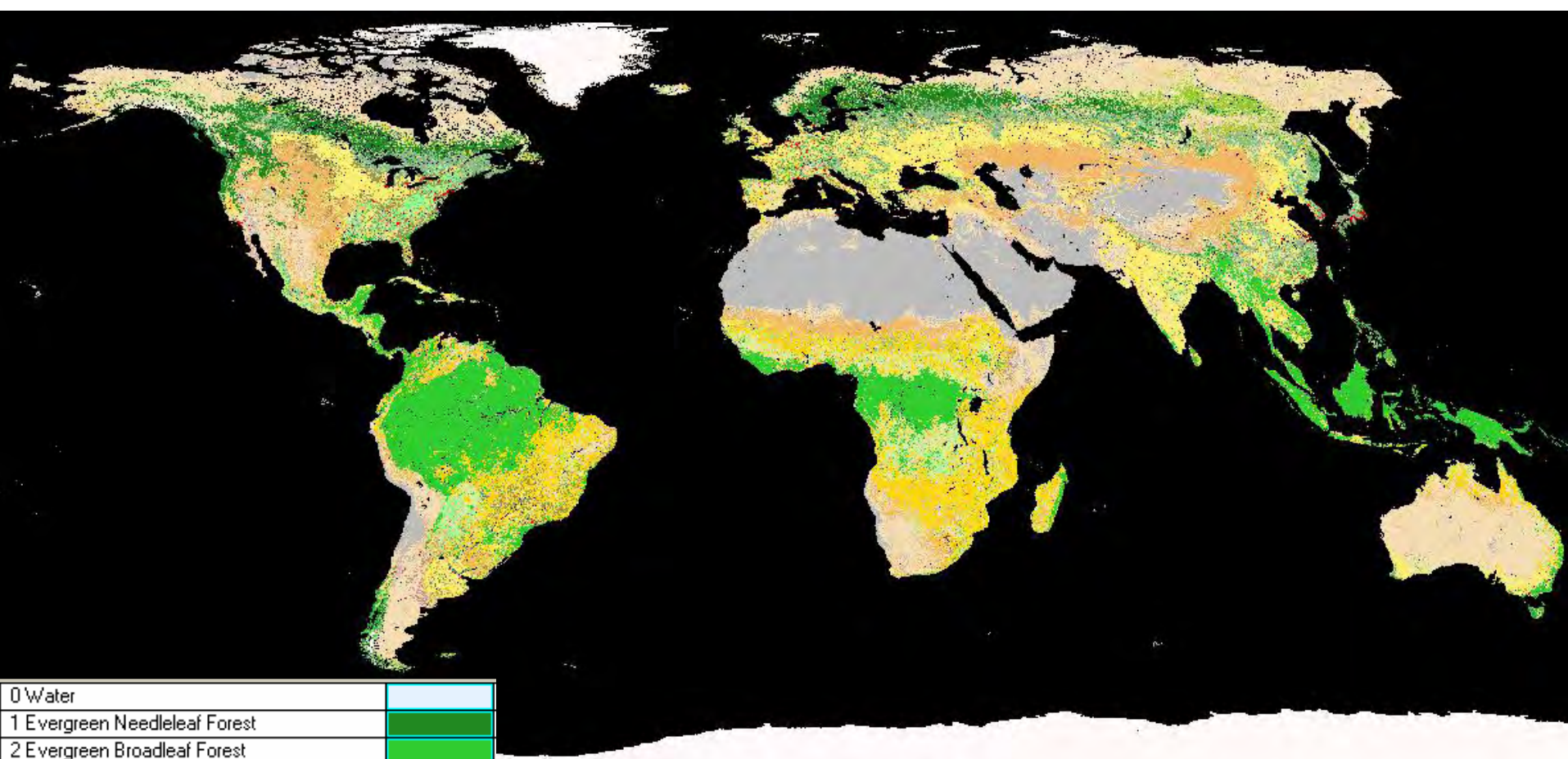


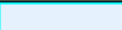



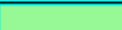












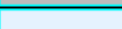
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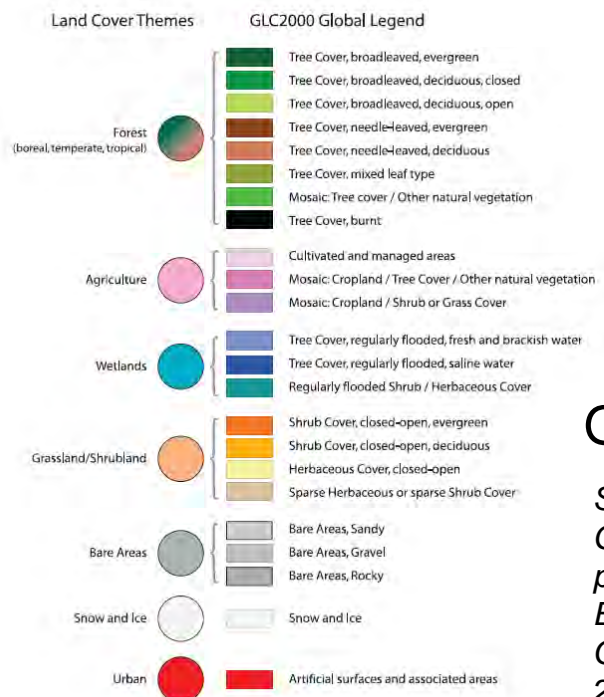
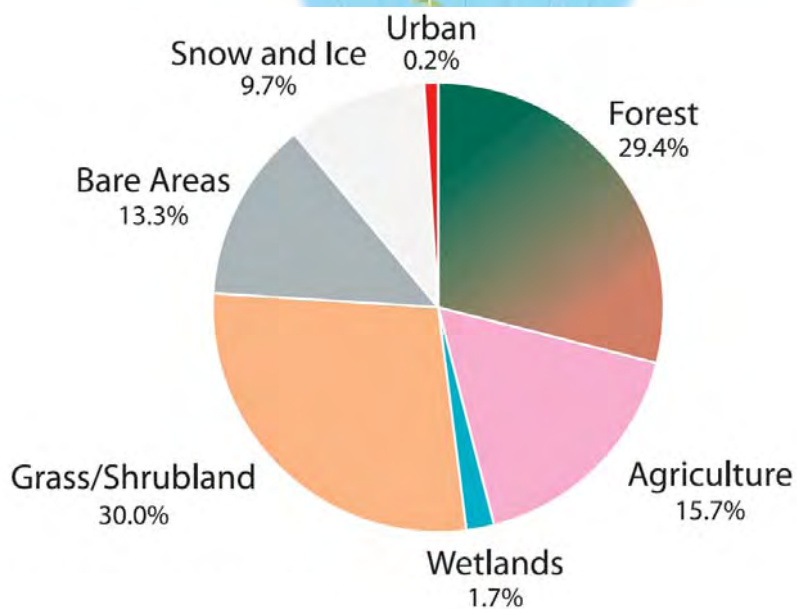
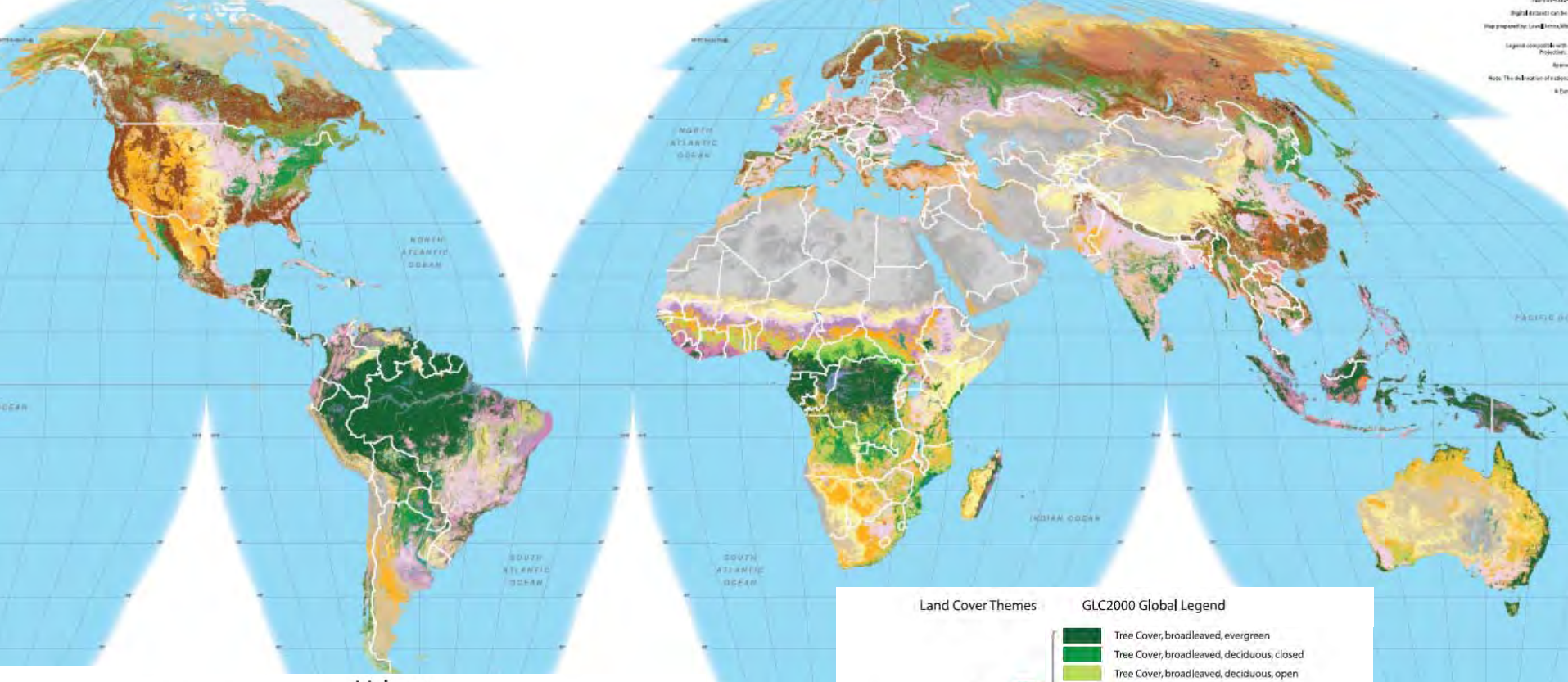


Timeline for Global Urban Maps





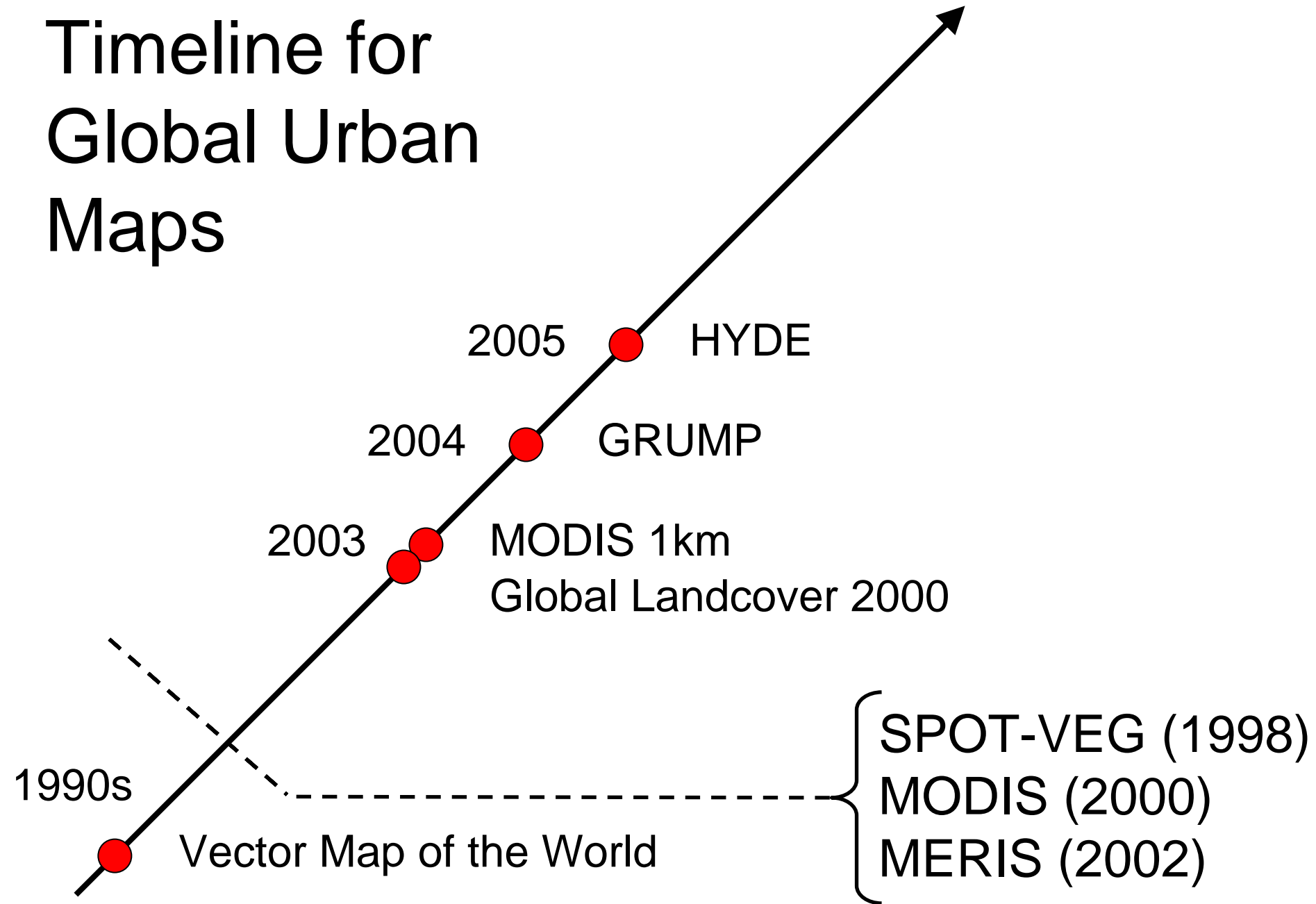
0 Water	
1 Evergreen Needleleaf Forest	
2 Evergreen Broadleaf Forest	
3 Deciduous Needleleaf Forest	
4 Deciduous Broadleaf Forest	
5 Mixed Forests	
6 Closed Shrublands	
7 Open Shrublands	
8 Woody Savannas	
9 Savannas	
10 Grasslands	
11 Permanent Wetlands	
12 Croplands	
13 Urban and Built-Up	
14 Cropland/Natural Vegetation Mosaic	
15 Snow and Ice	
16 Barren or Sparsely Vegetated	
17 (Water Bodies, recoded to 0)	



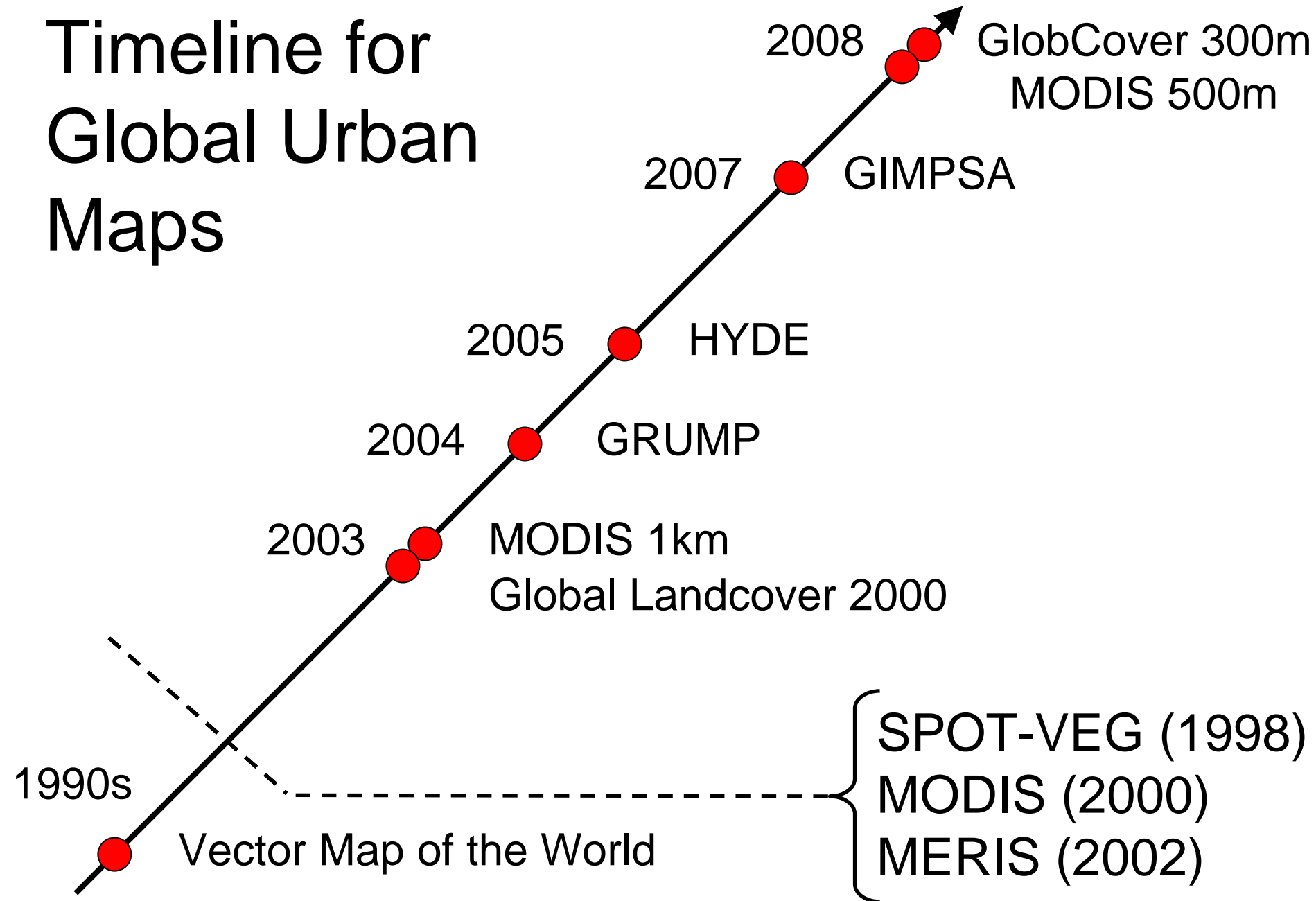
GLC 2000

*Source:
GLC2000
poster,
European
Commission,
2004.*

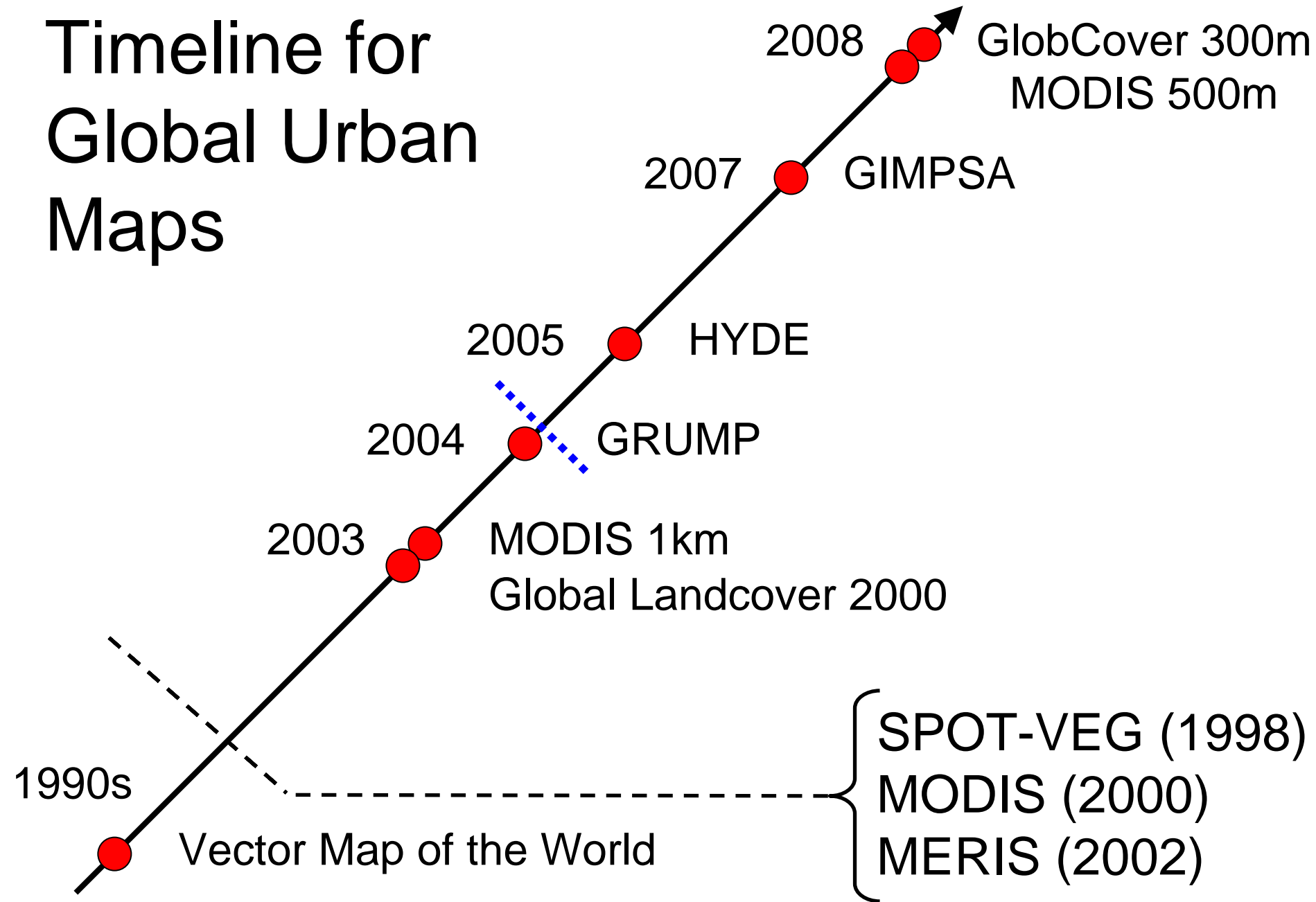
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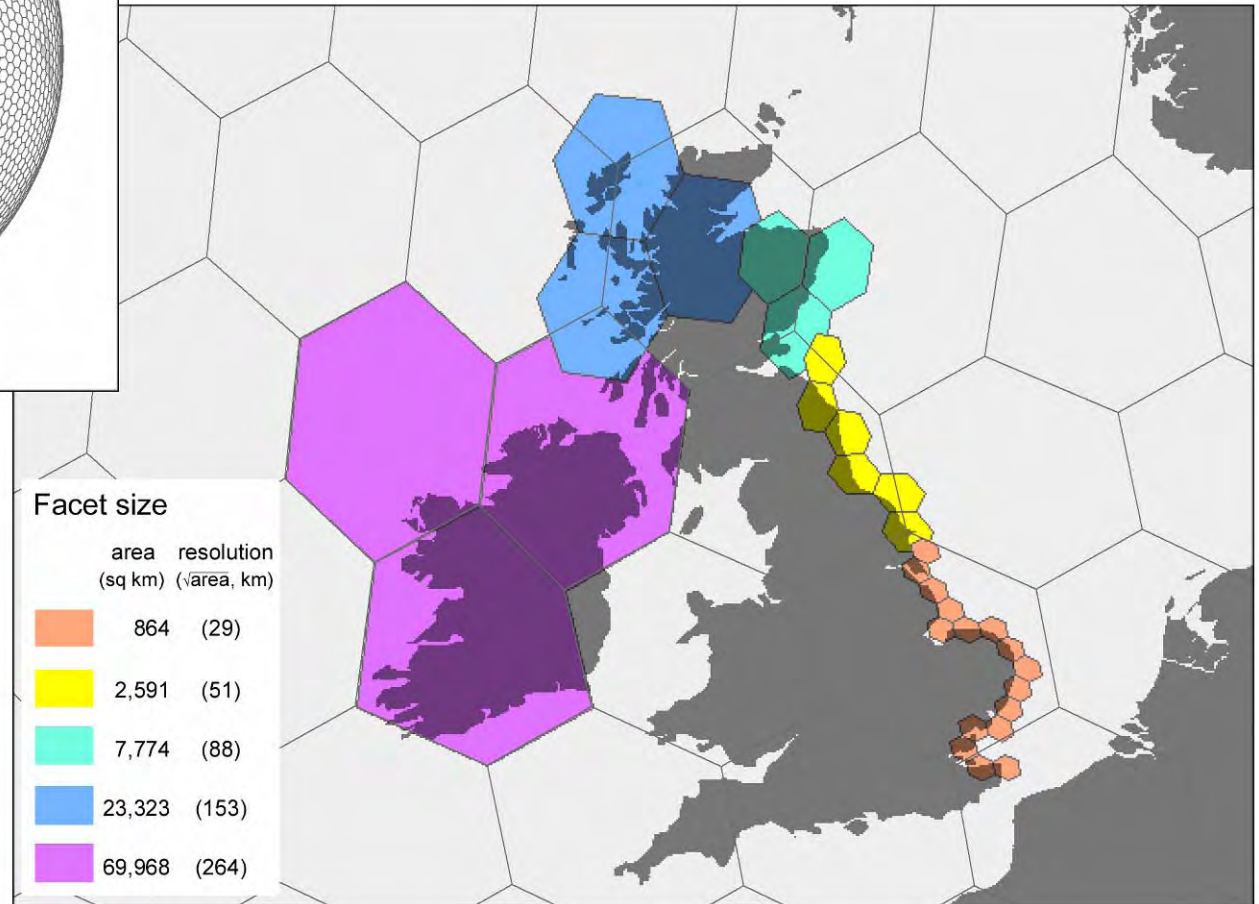
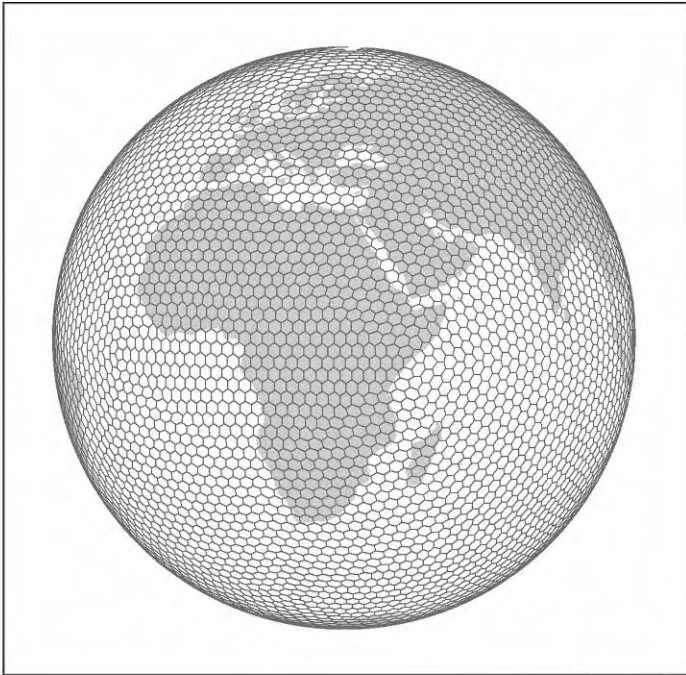
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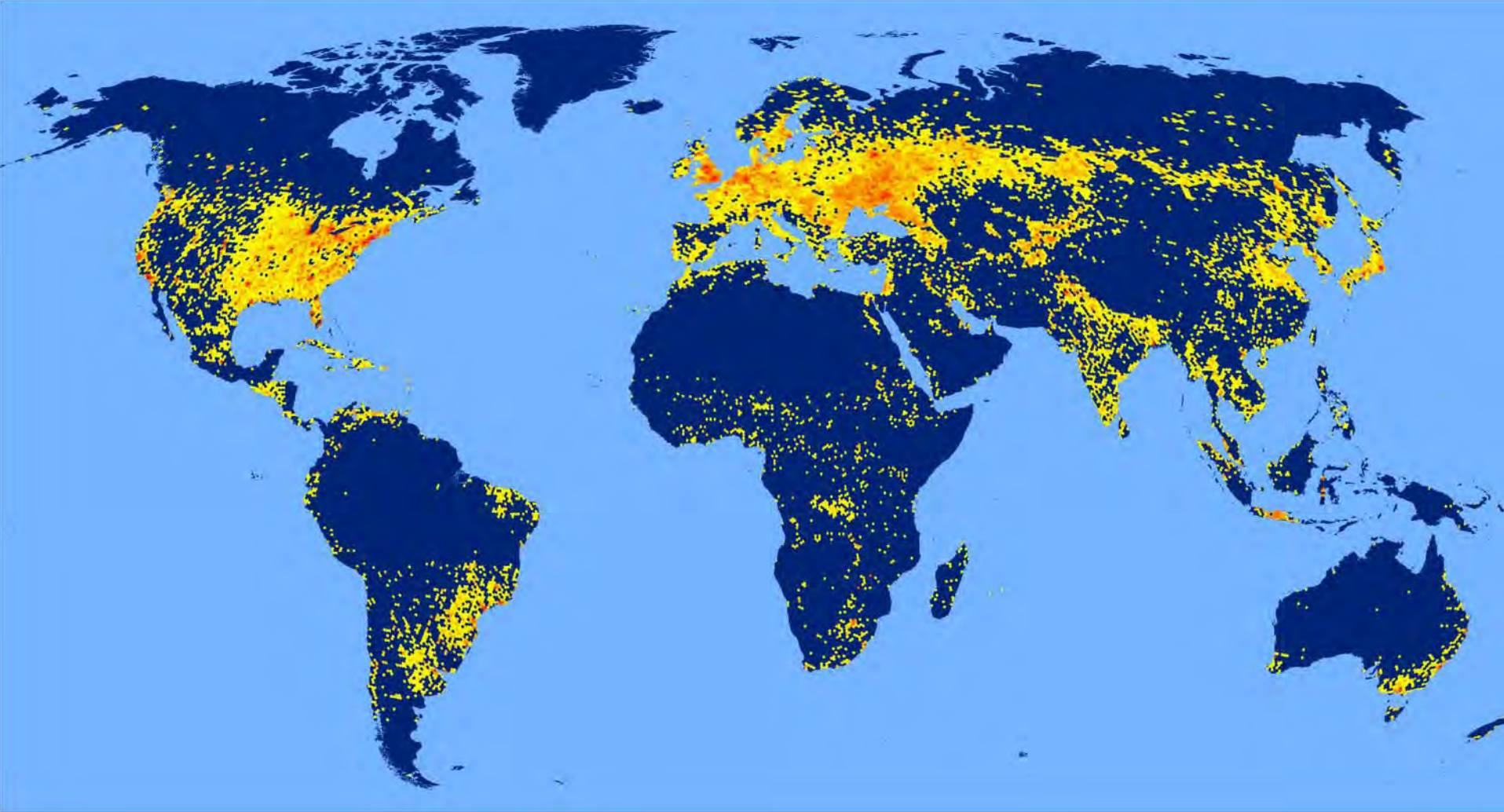
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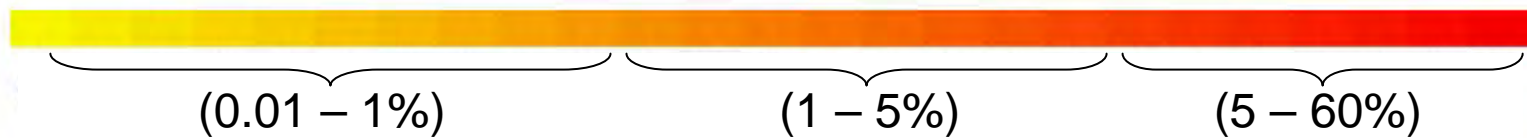
Map visualization with Discrete Global Grids



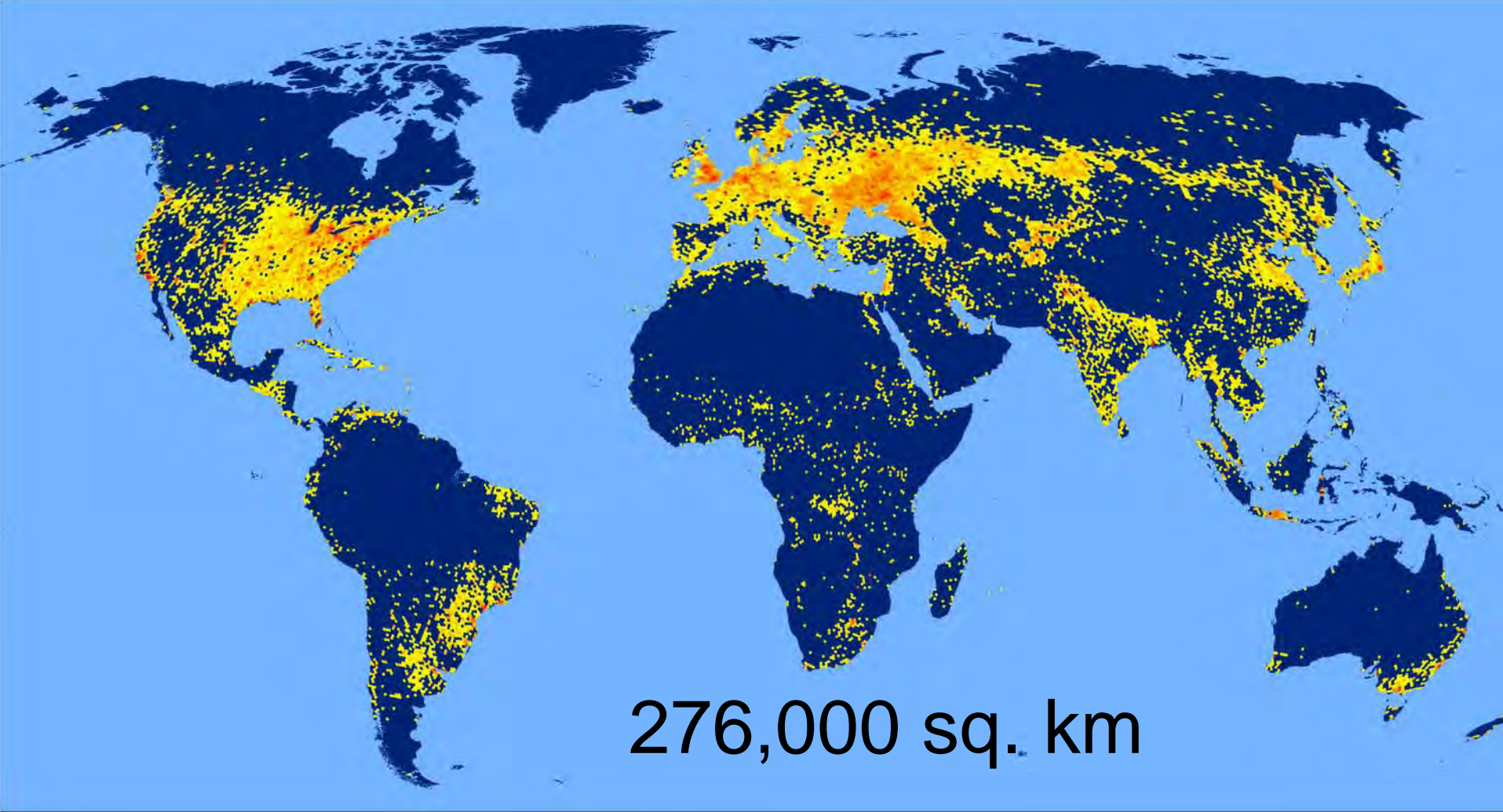
Sahr *et al.*, 2003.
Birch *et al.*, 2007.



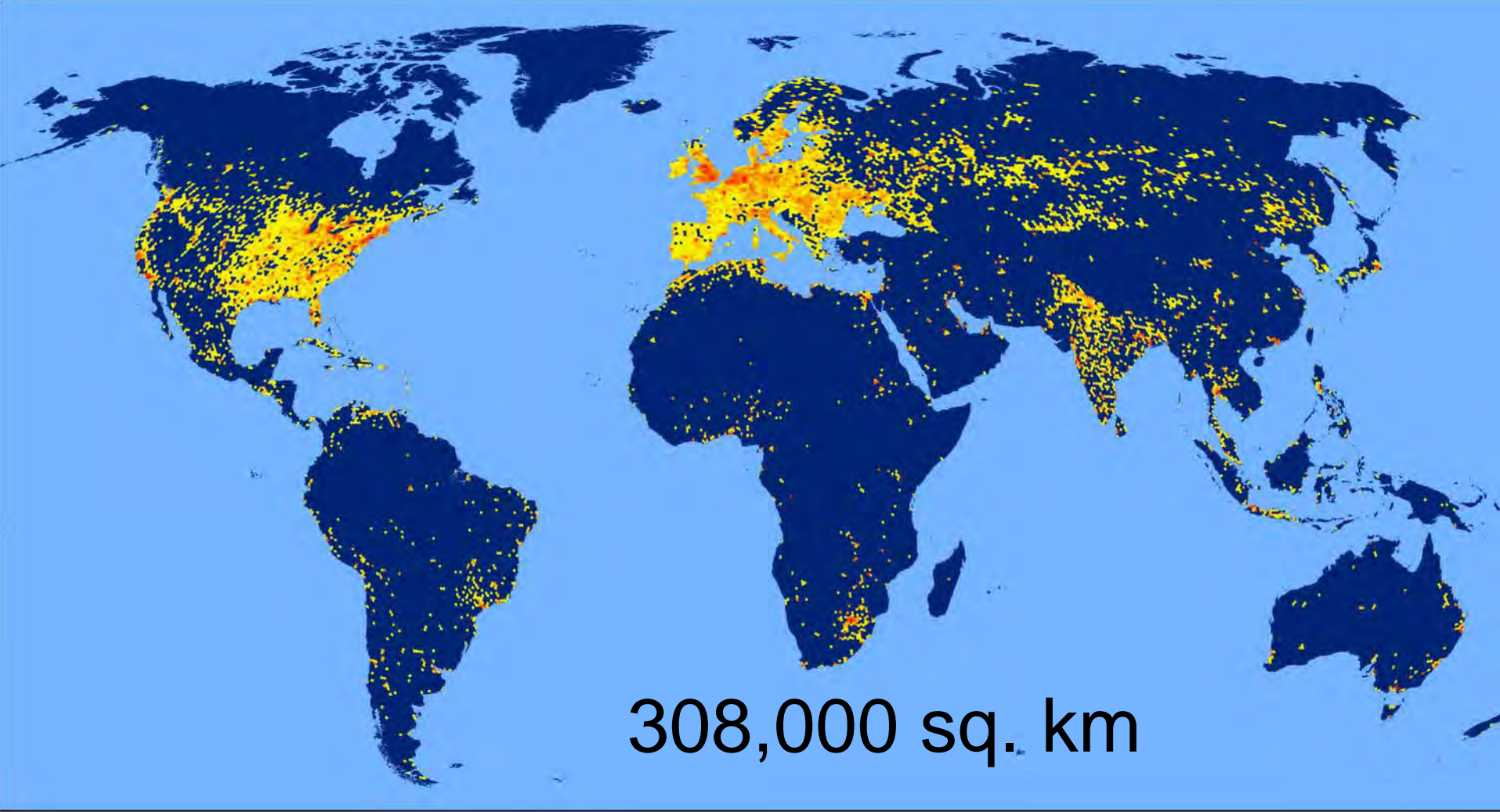
mean percent
urban within each
2500 sq km
hexagonal cell



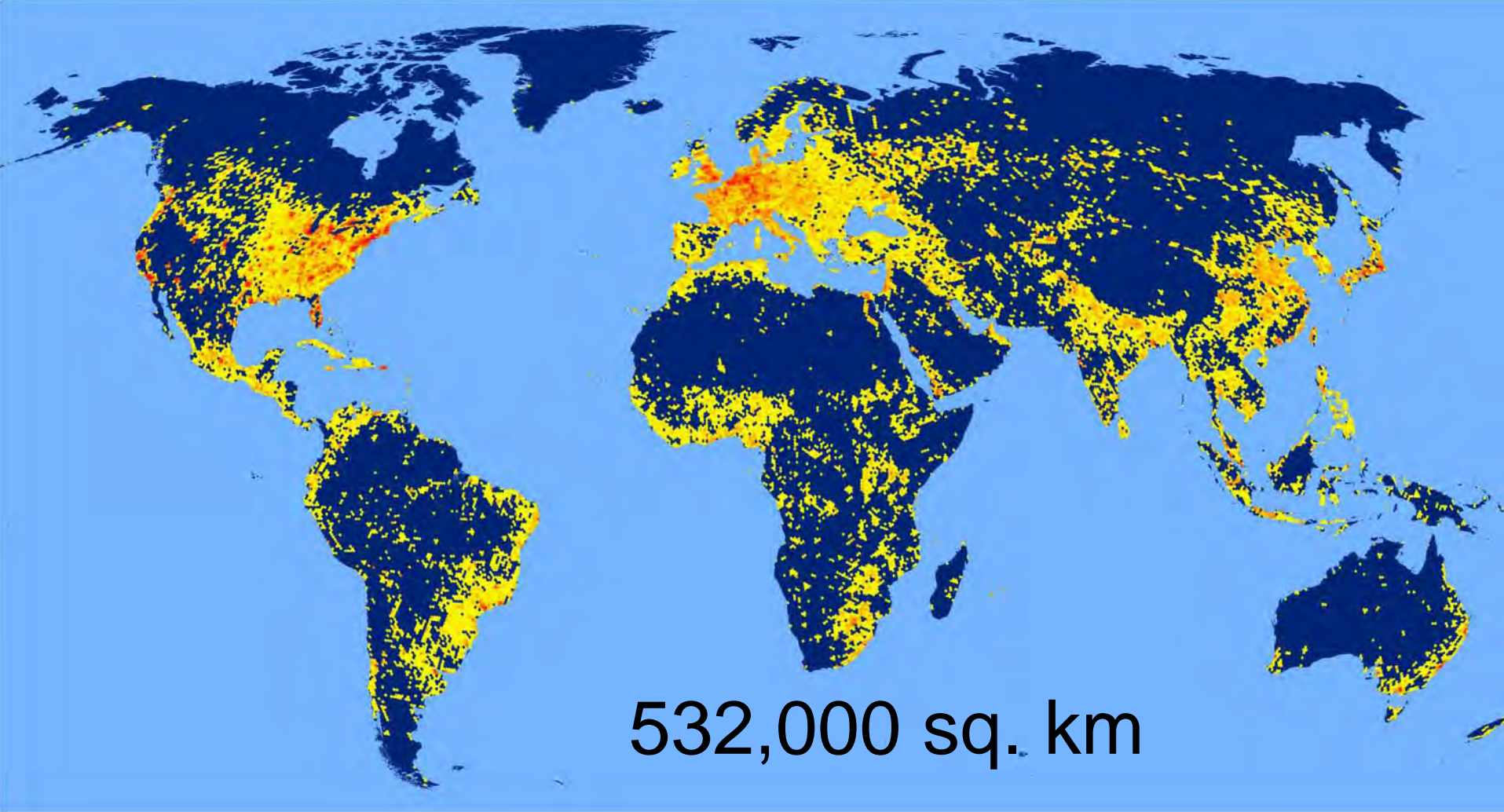
Potere and Schneider, 2008.



Vector Map Level Zero



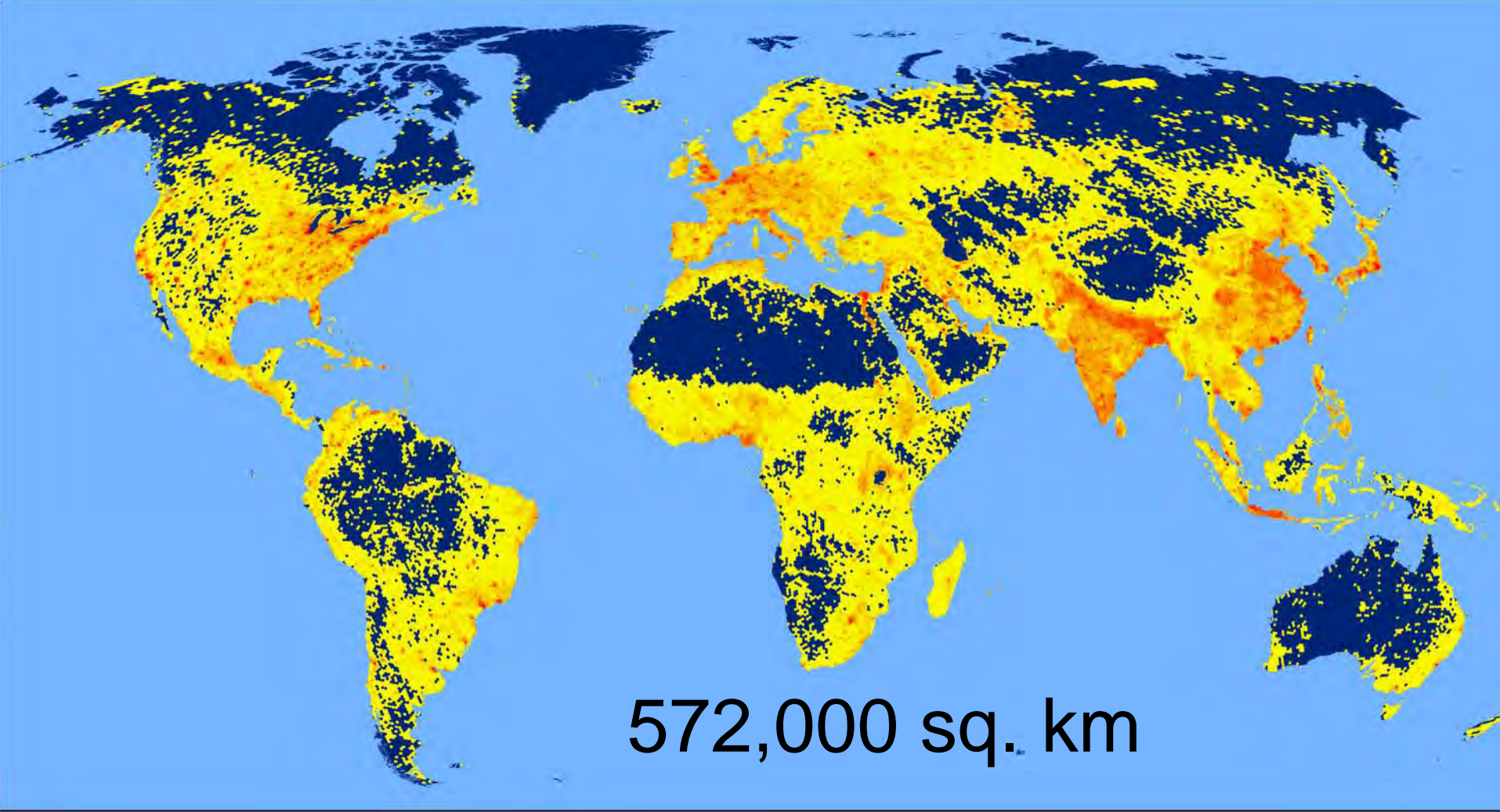
Global Landcover 2000



532,000 sq. km

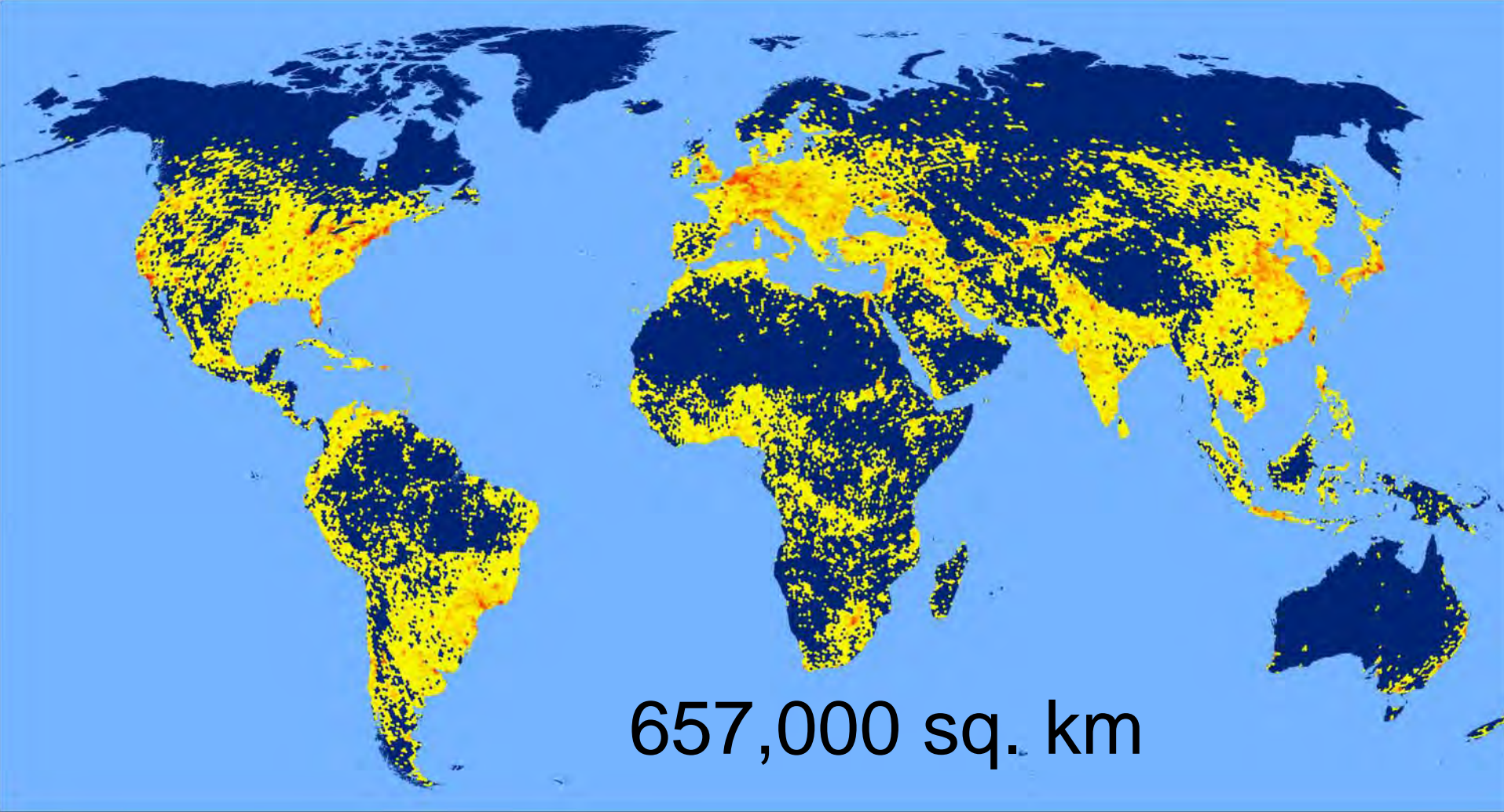
History Database of the Global Environment v3

Potere and Schneider, 2008.

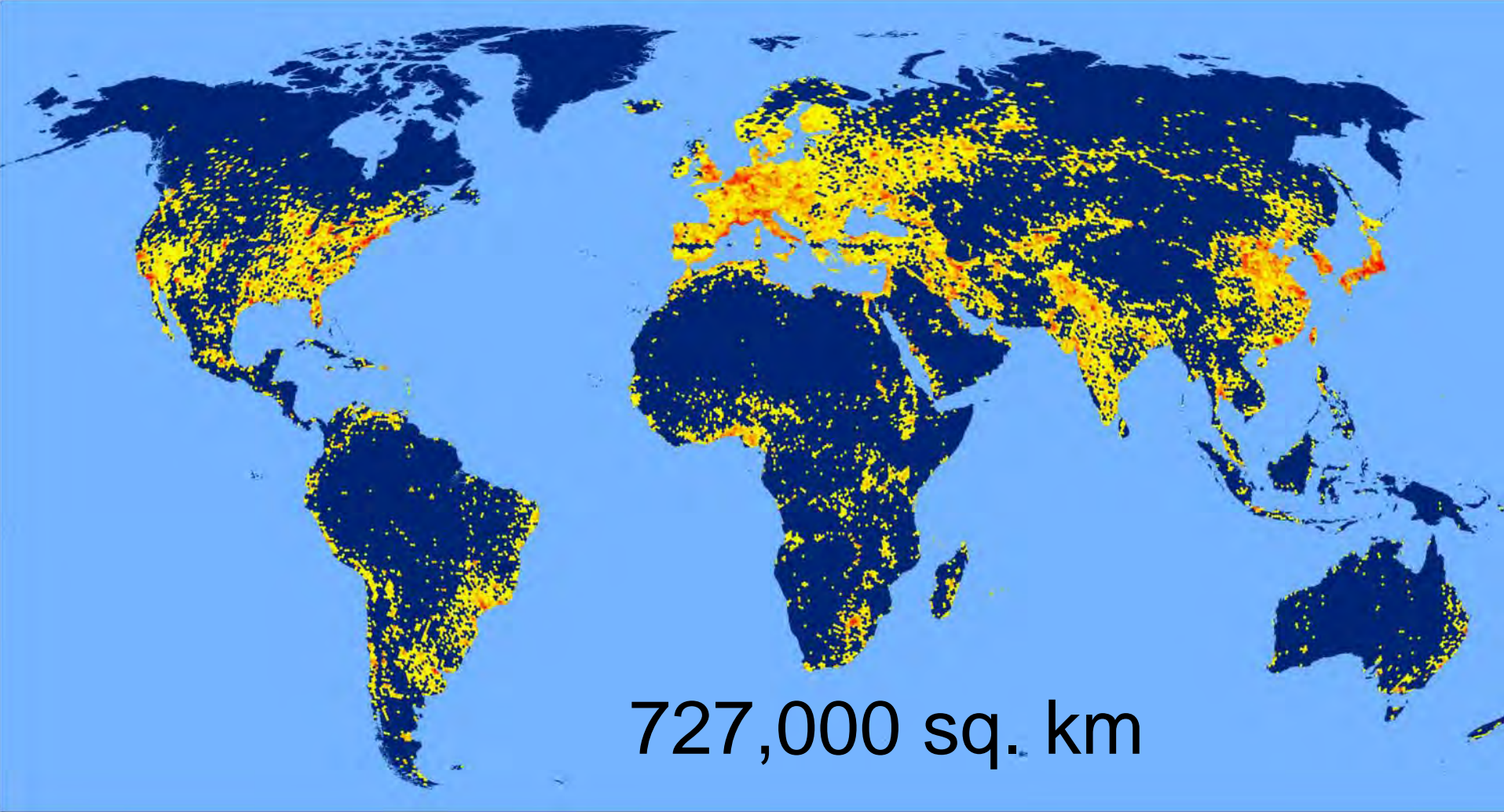


Global Impervious Surface Area

Potere and Schneider, 2008.

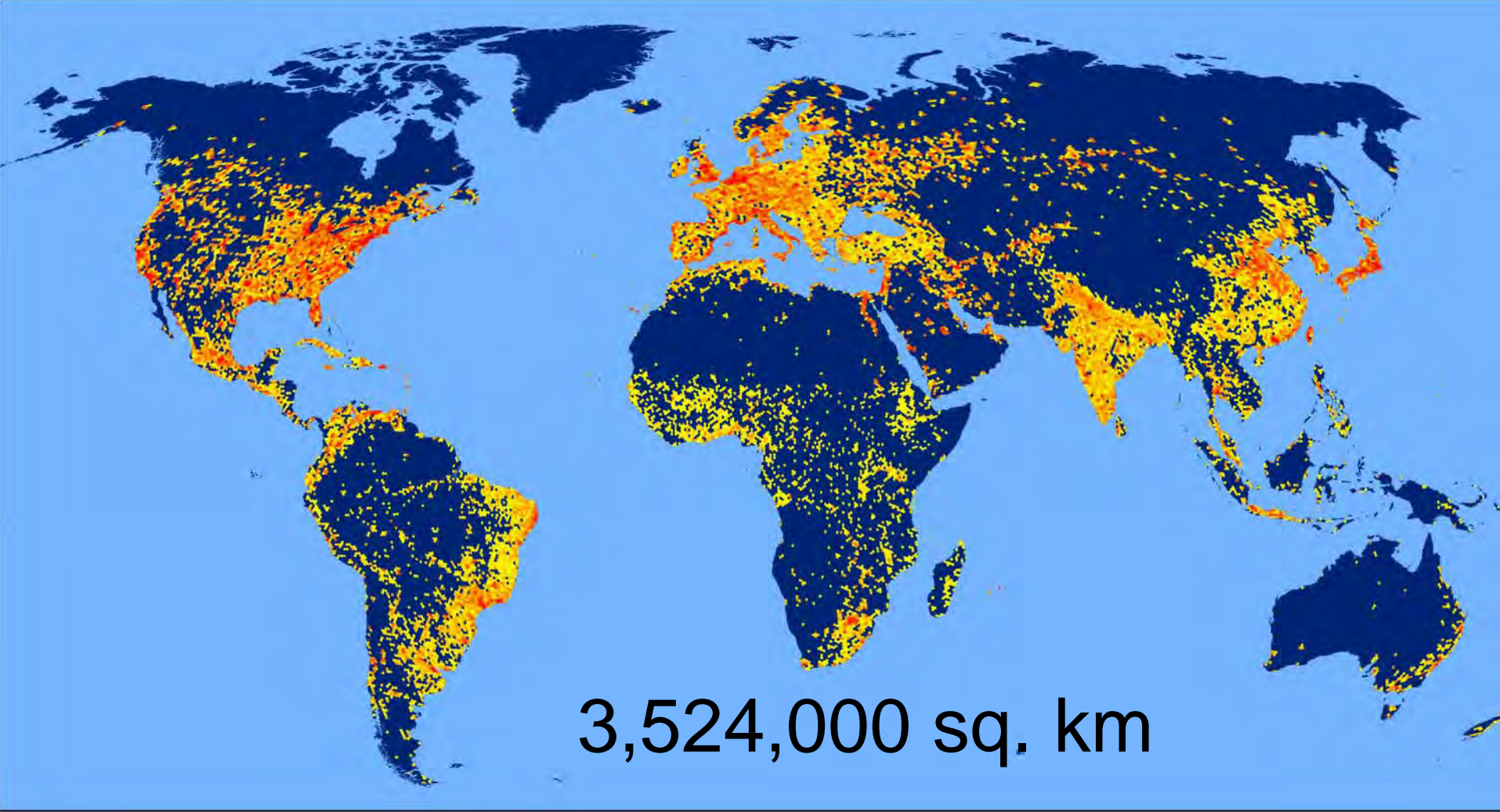


MODIS 500m urban



727,000 sq. km

MODIS 1km urban



Global Rural Urban Mapping Project (GRUMP)

Potere and Schneider, 2008.

Choosing a global urban map

Global scope

Adequate spatial resolution (500 m – 1 km)

Current (circa-2000)

Choosing a global urban map

Global scope

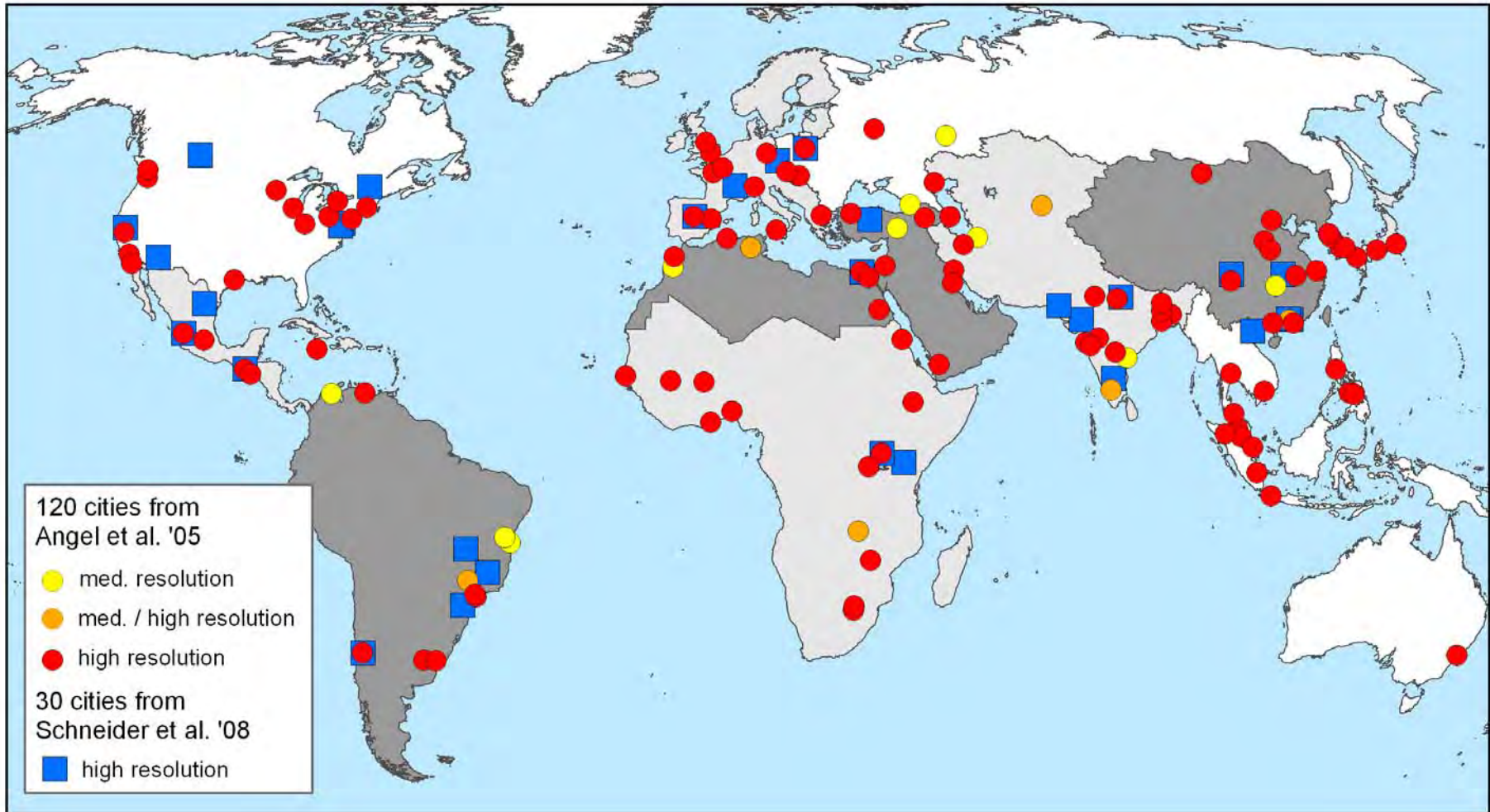
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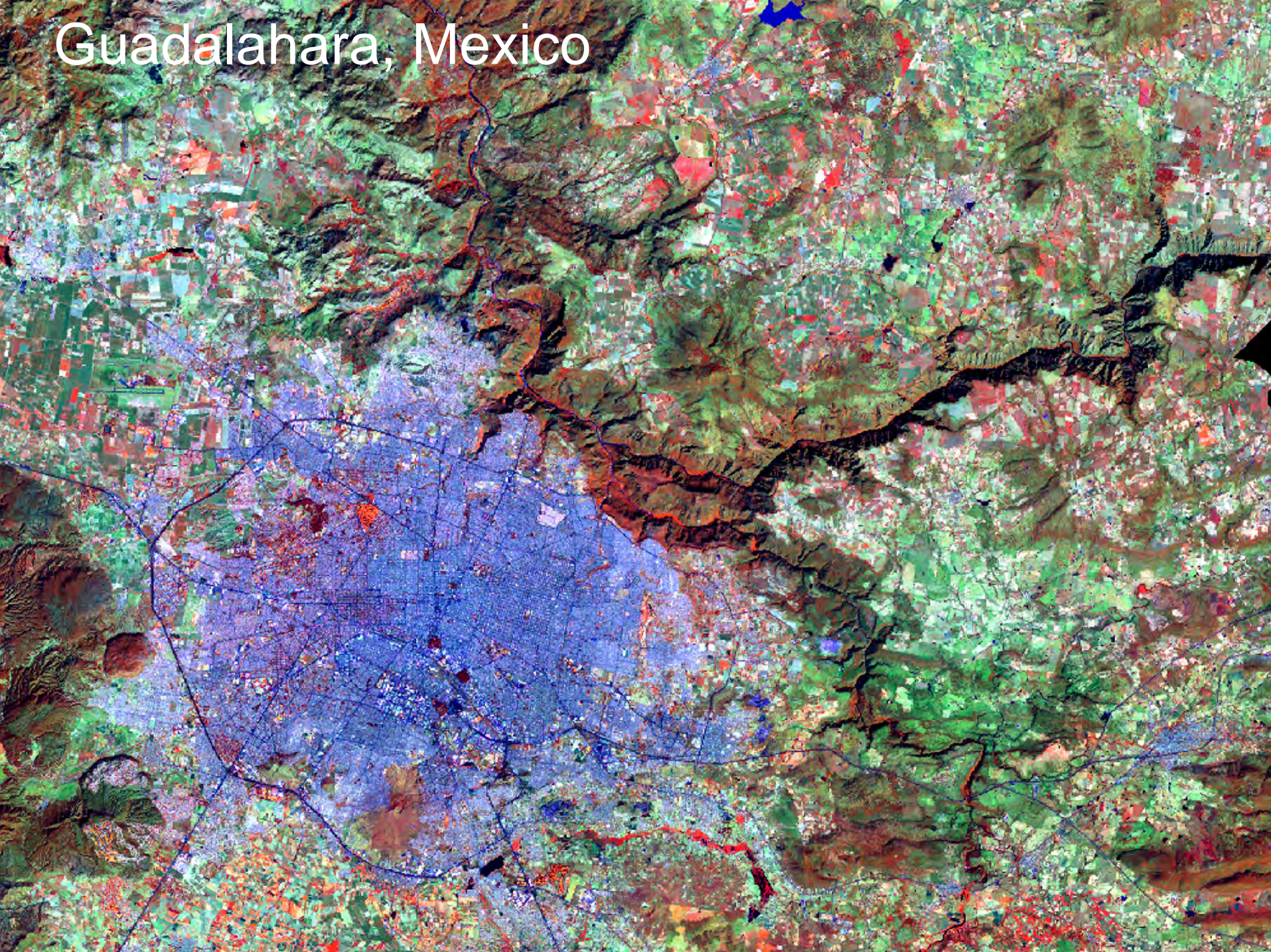
Accurate

- Includes all major cities
- Maps city shape correctly
- Maps city size correctly

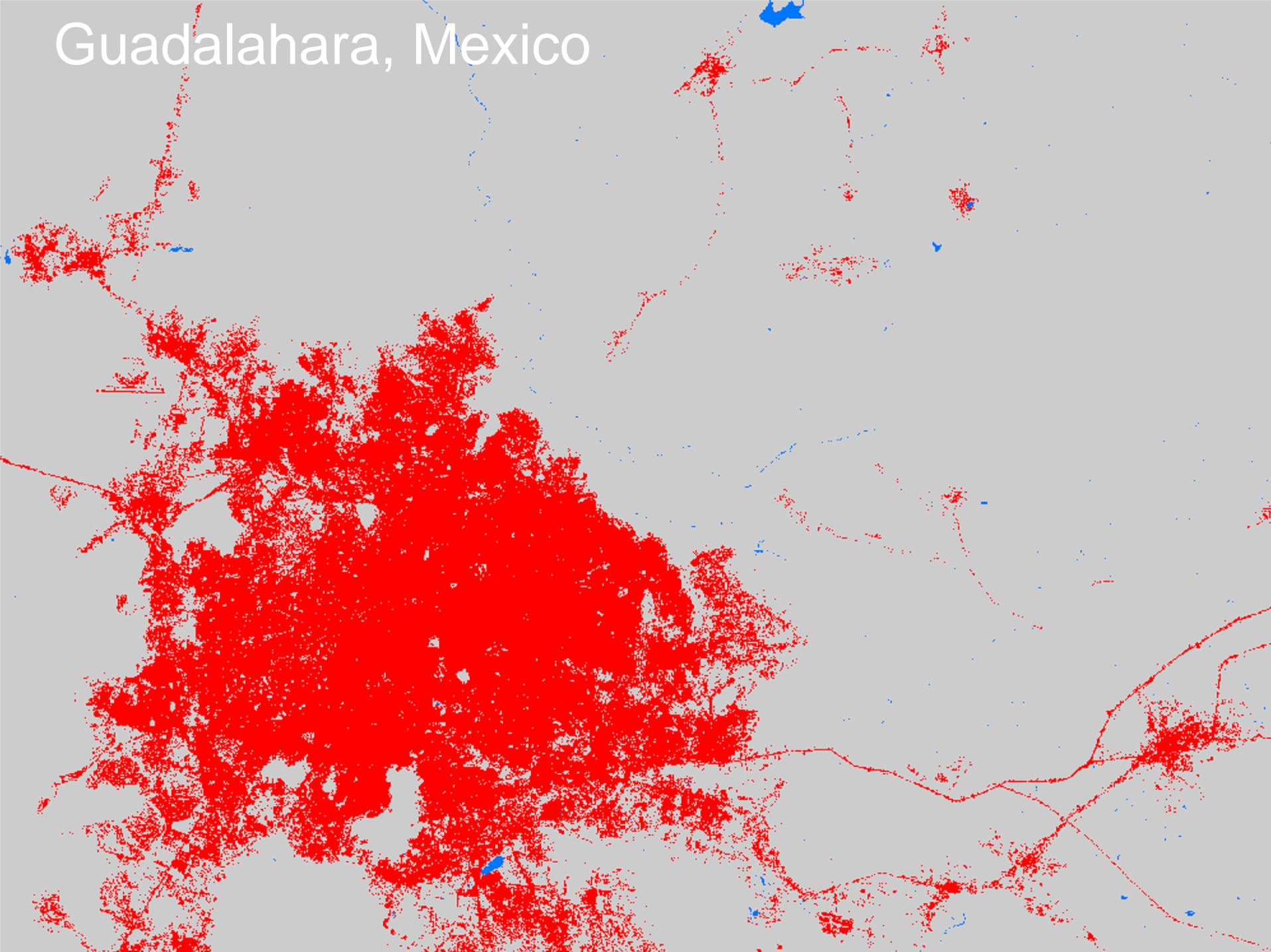
Landsat city maps for accuracy assessment



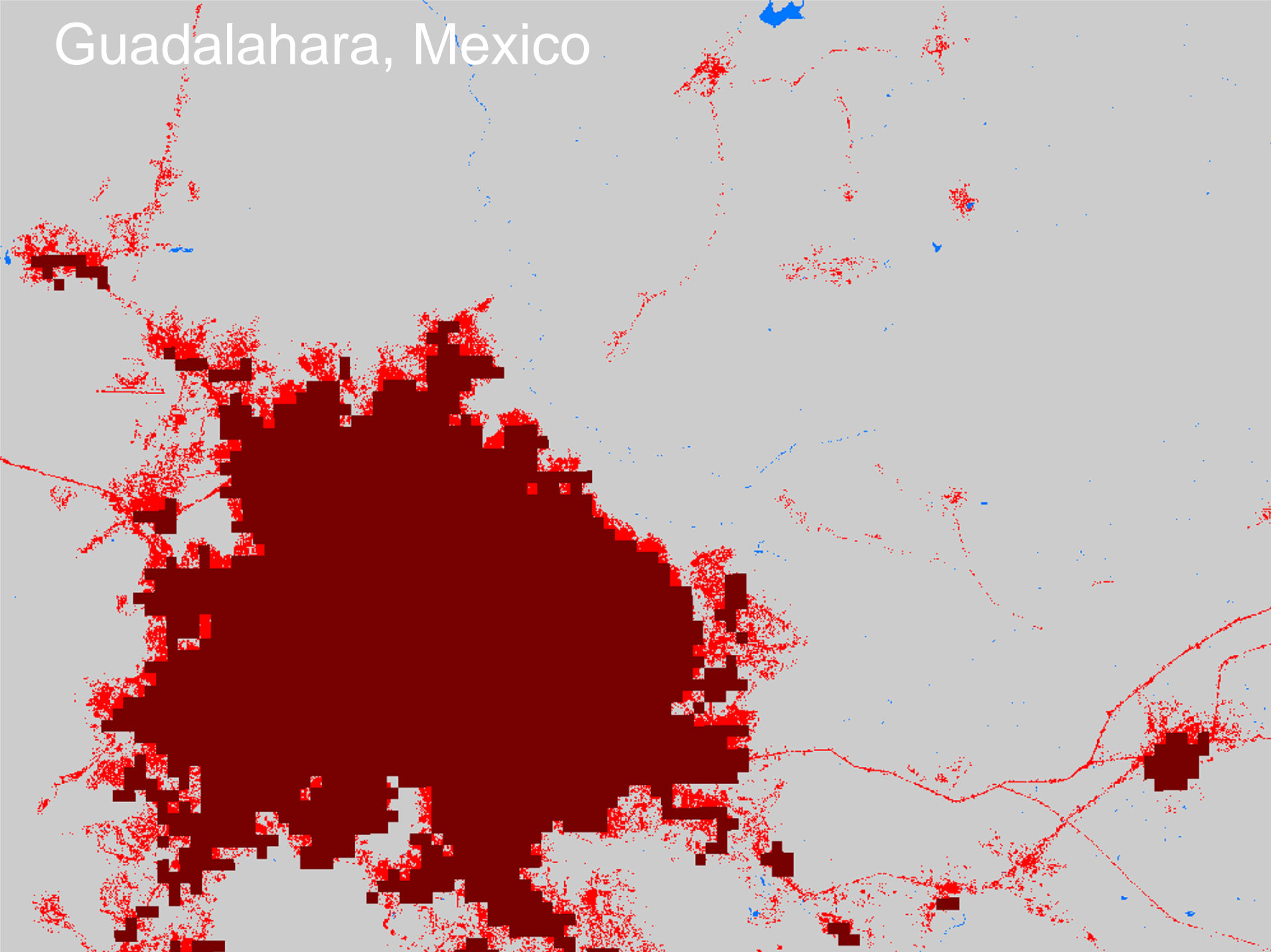
Guadalajara, Mexico



Guadalajara, Mexico



Guadalajara, Mexico



Canada, St. Catharines : Site 2



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

Scene Elements

(no more than five)

residential

- ☐ high density
- ☐ low density
- ☐ single houses
- ☐ slum, informal

built-up

- ☐ industrial, commercial, institutional
- ☐ roads, airports, ports
- ☐ mines, quarries, construction

agriculture

- ☐ large fields, pasture
- ☐ small fields, pasture
- ☐ vineyards, nurseries, plantations

undeveloped land

- ☐ forest, tundra
- ☐ savanna, shrubs, grasses
- ☐ barren, desert, rock

water

- ☐ permanent ice
- ☐ wetland, marsh
- ☐ water, river, lake, canal
- ☐ flooded land

unknown

- ☐ cloud cover
- ☐ low resolution
- ☐ other

Submit

Clear

Canada, St. Catharines : Site 6



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

Scene Elements

(no more than five)

- residential
 - ☐ high density
 - ☐ low density
 - ☐ single houses
 - ☐ slum, informal
- built-up
 - ☐ indust'l, commerc'l, institut'l
 - ☐ roads, airports, ports
 - ☐ mines, quarries, construction
- agriculture
 - ☐ large fields, pasture
 - ☐ small fields, pasture
 - ☐ vineyards, nurseries, plantations
- undeveloped land
 - ☐ forest, tundra
 - ☐ savanna, shrubs, grasses
 - ☐ barren, desert, rock
 - ☐ permanent ice
- water
 - ☐ wetland, marsh
 - ☐ water, river, lake, canal
 - ☐ flooded land
- unknown
 - ☐ cloud cover
 - ☐ low resolution
 - ☐ other

Submit

Clear

Canada, St. Catharines : Site 26



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

Scene Elements

(no more than five)

residential

- ☐ high density
- ☐ low density

built-up

- ☐ single houses
- ☐ slum, informal
- ☐ indust'l, commerc'l, institut'l
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- ☐ flooded land
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- ☐ other

Submit

Clear

Choosing a global urban map

Global scope

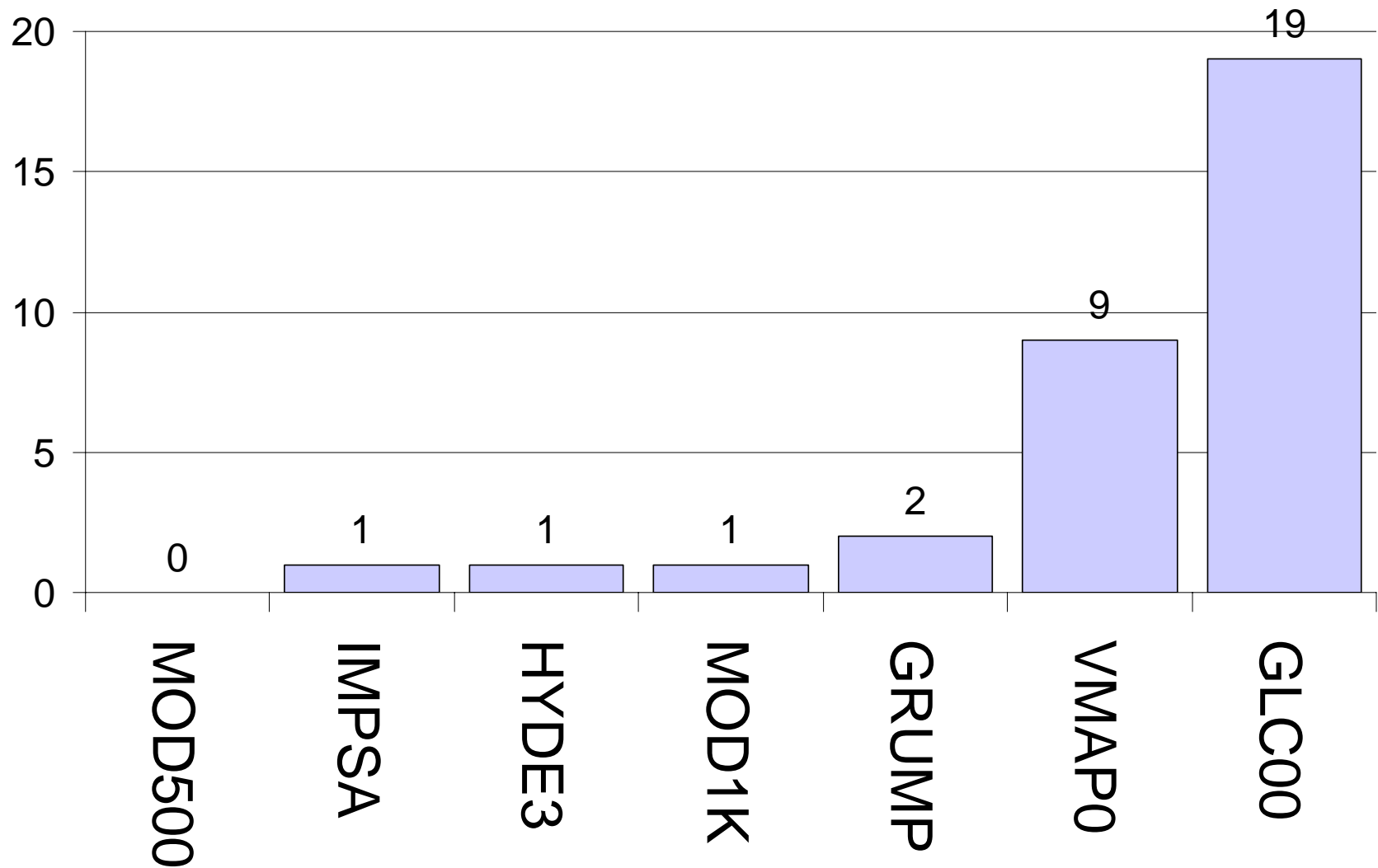
Adequate spatial resolution (500 m – 1 km)

Current (circa-2000)

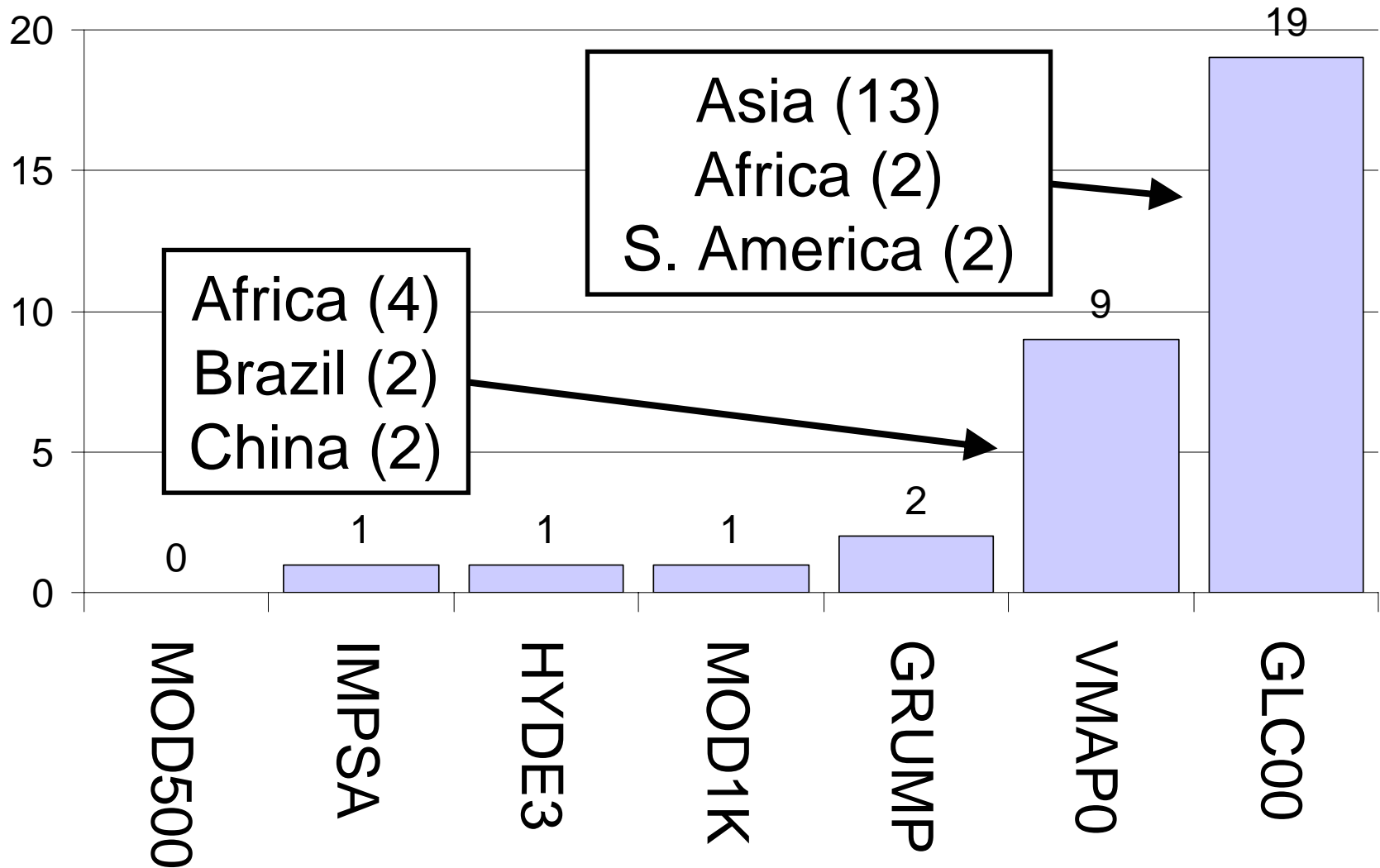
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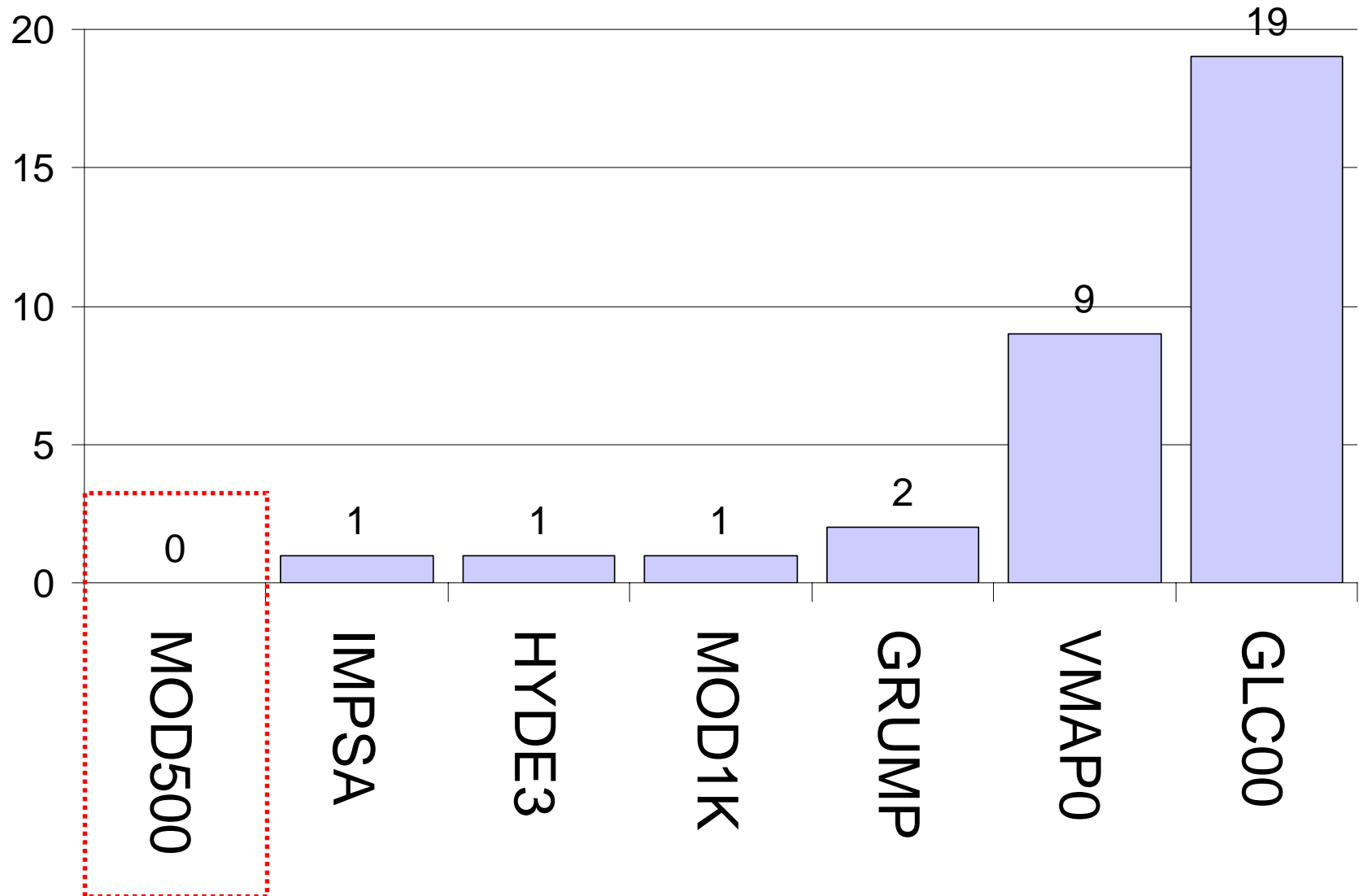
Omissions of major cities



Omissions of major cities



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Global scope

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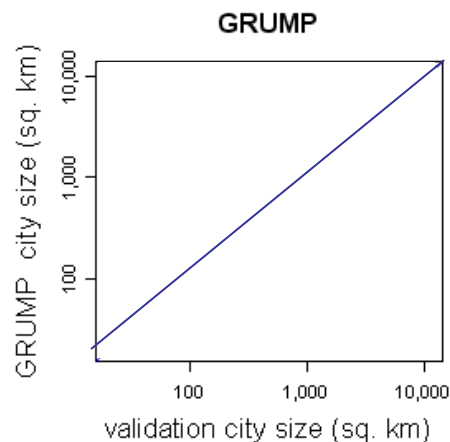
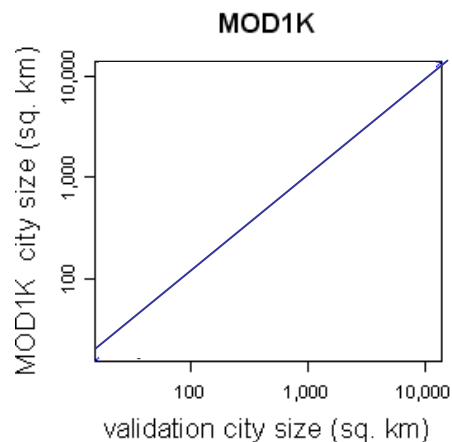
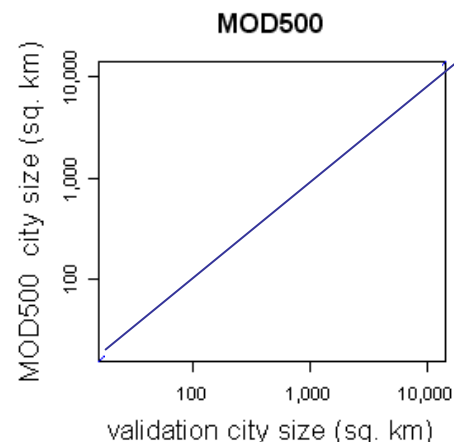
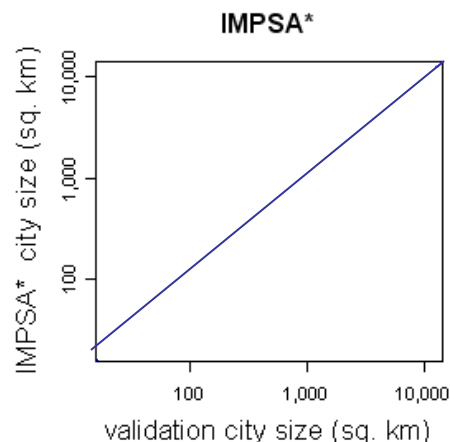
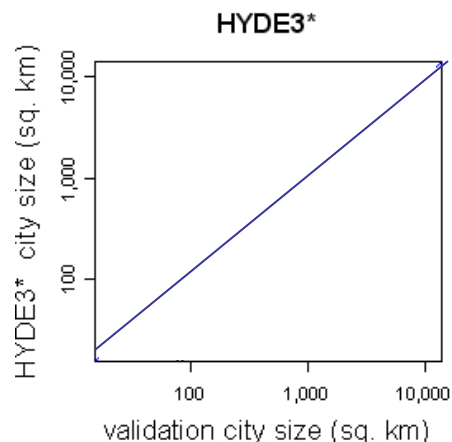
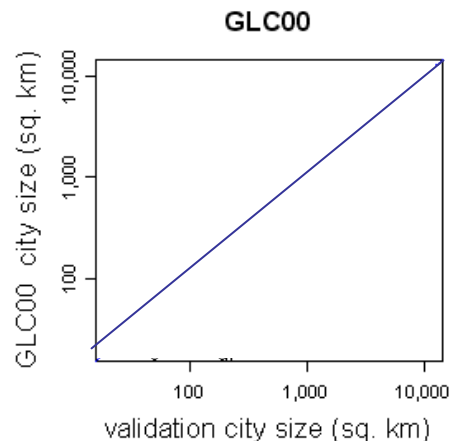
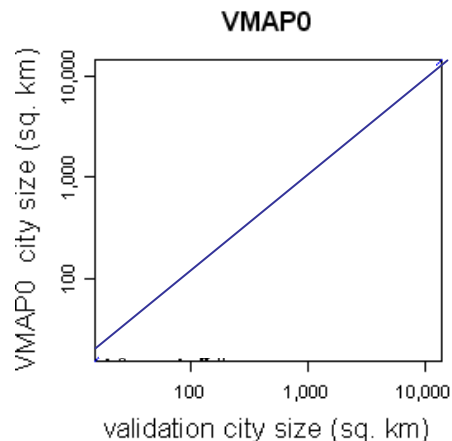
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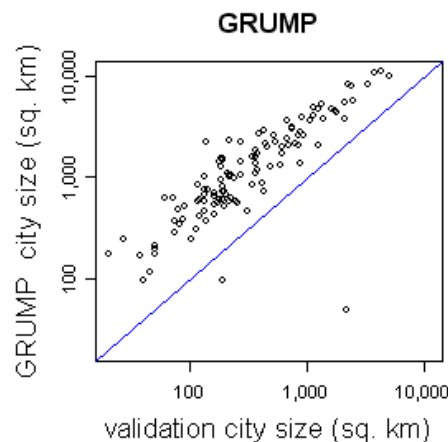
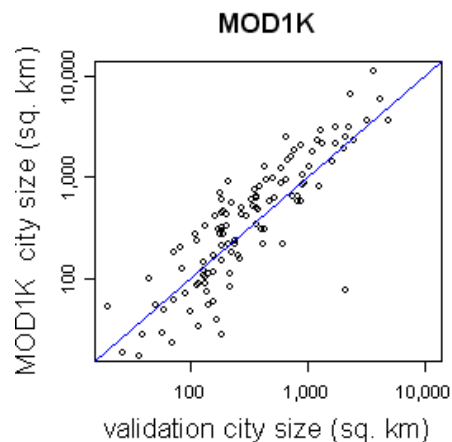
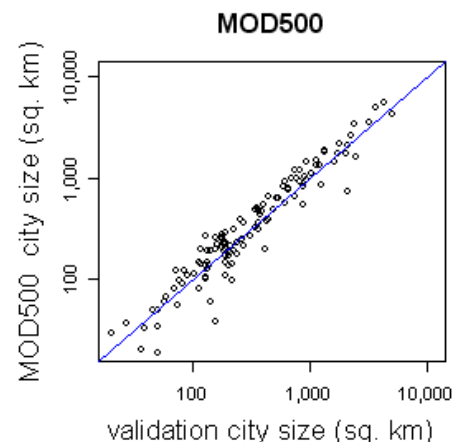
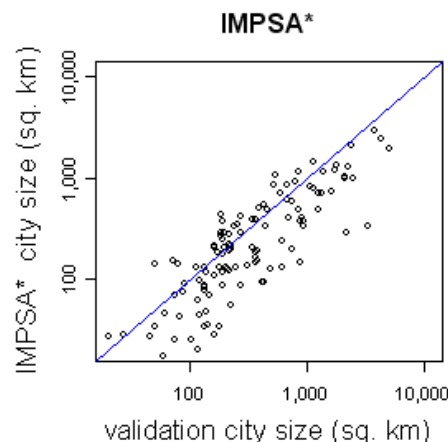
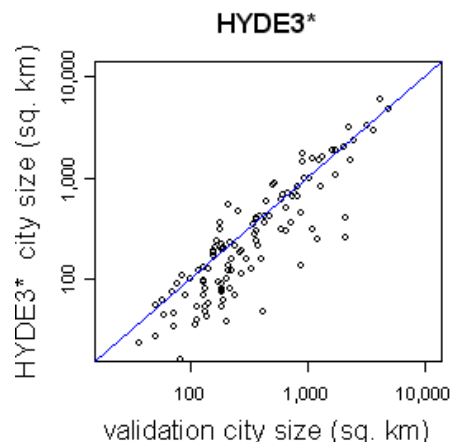
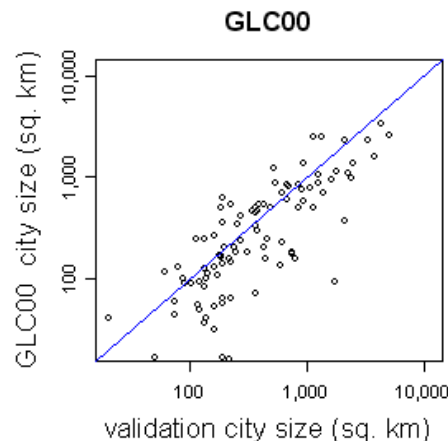
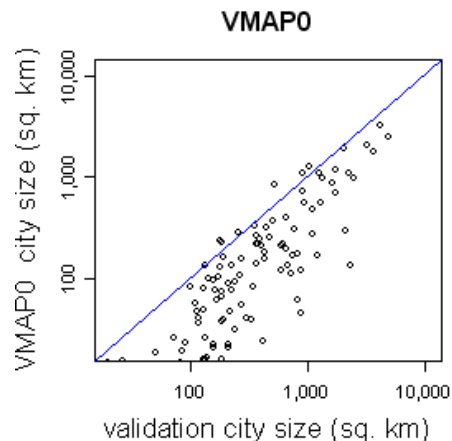
Scatter-plots of city size (n=120)

Landsat vs. 7 Global Urban Maps



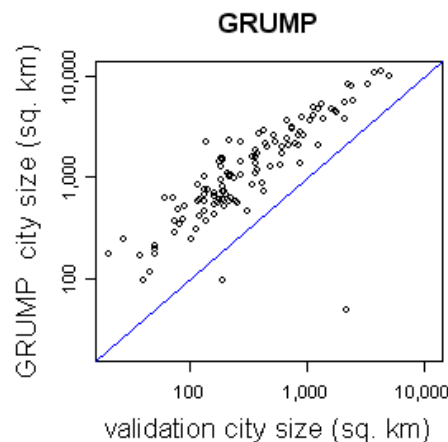
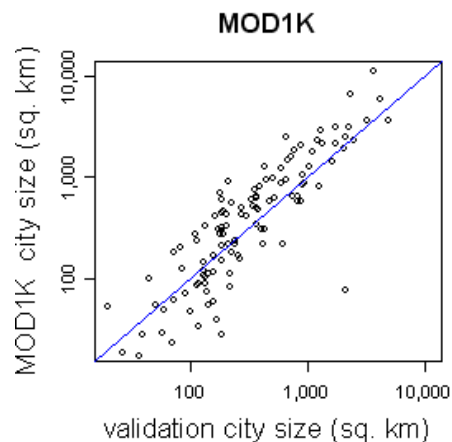
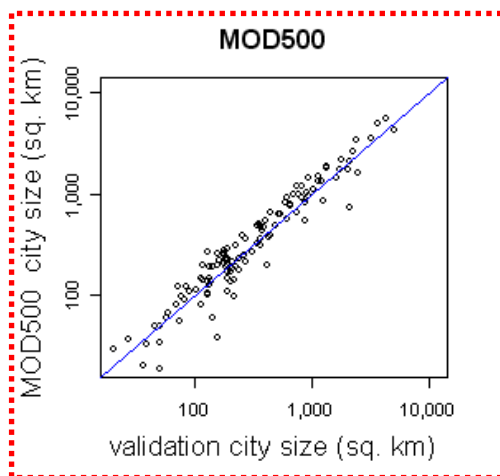
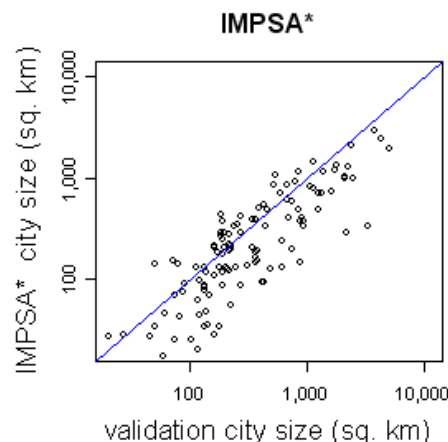
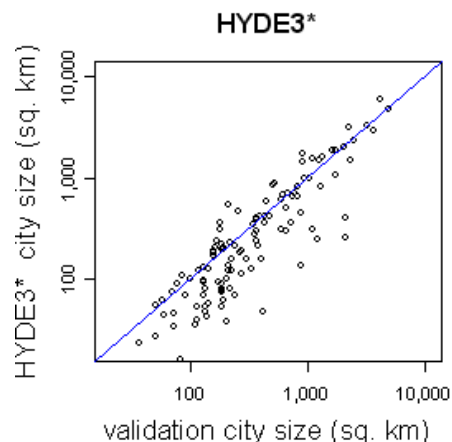
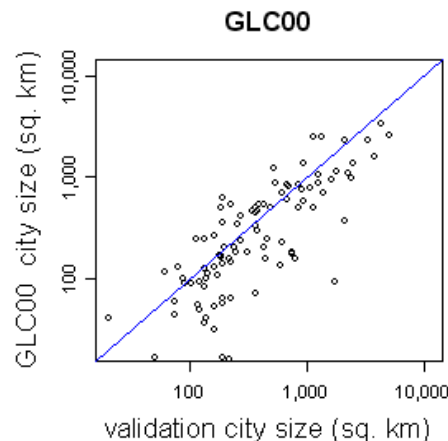
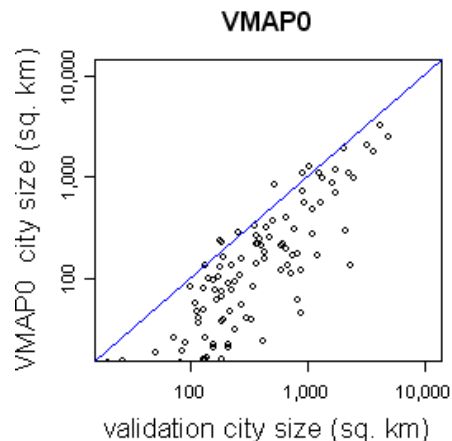
Scatter-plots of city size (n=120)

Landsat vs. 7 Global Urban Maps



Scatter-plots of city size (n=120)

Landsat vs. 7 Global Urban Maps



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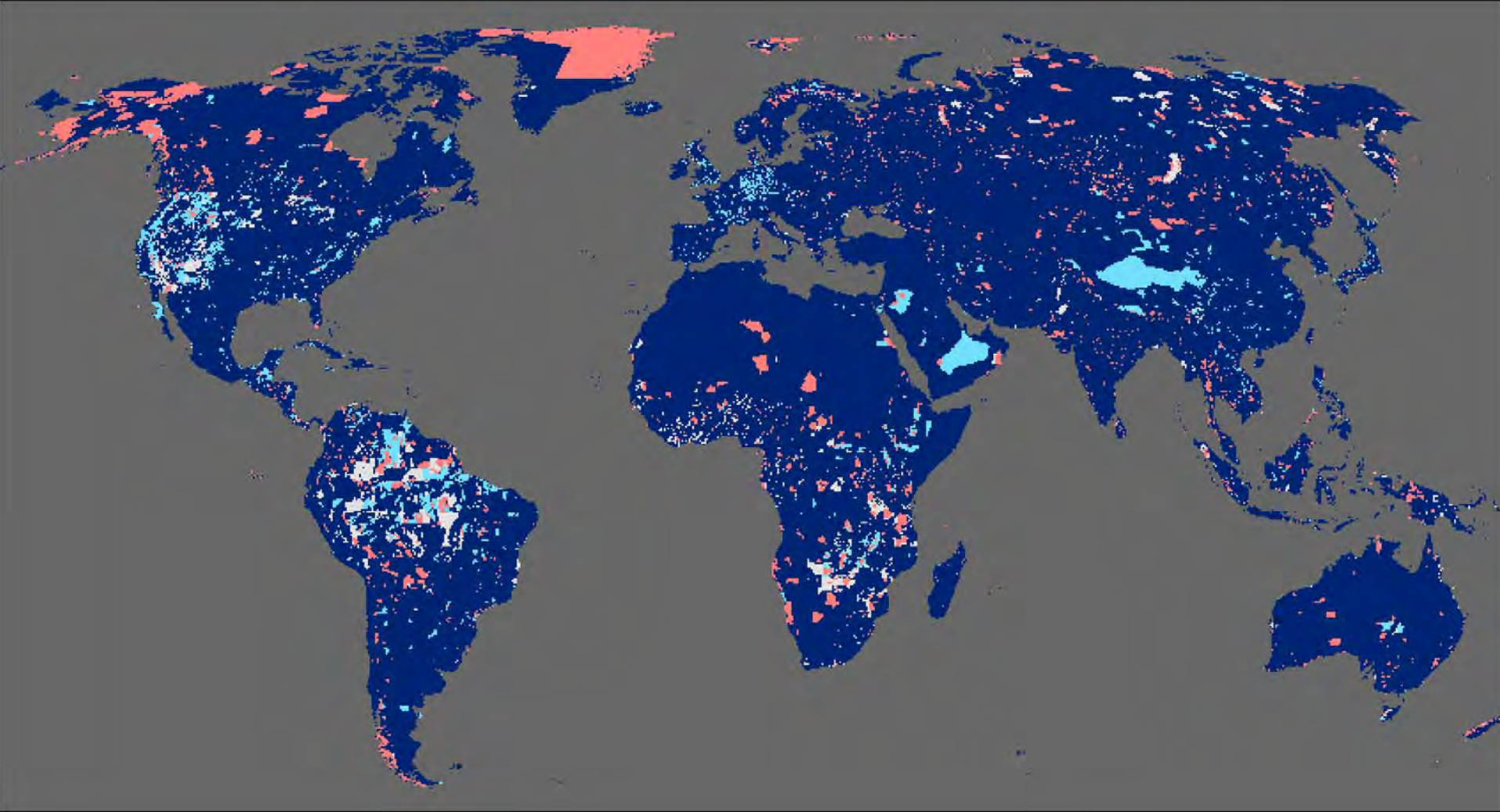
Why global urban maps?


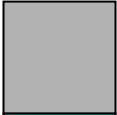
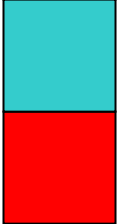
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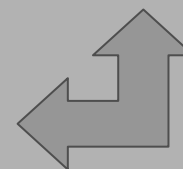
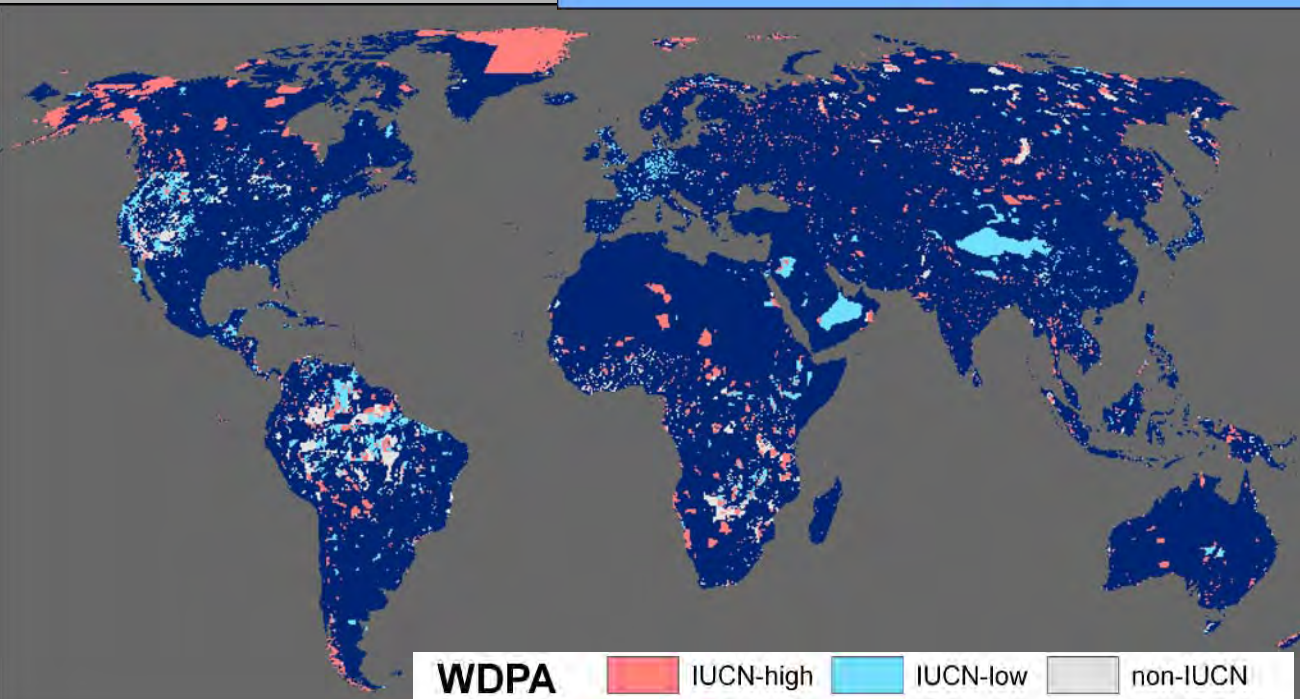
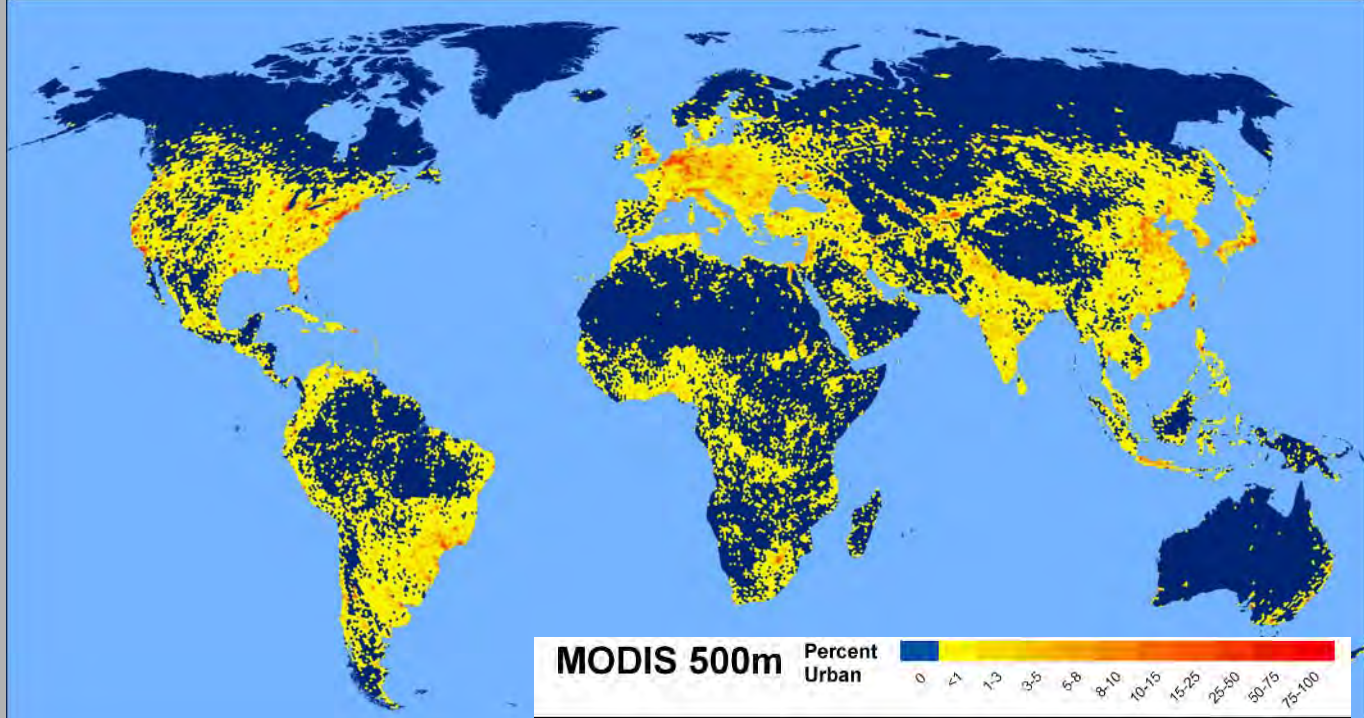
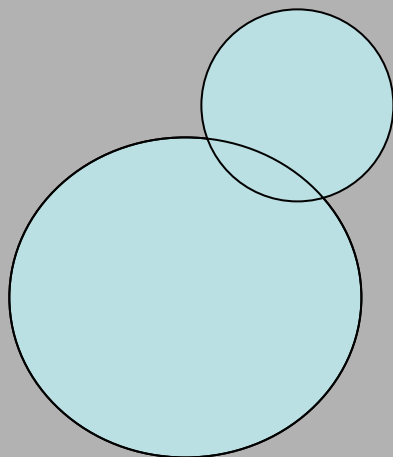
Urban expansion and conservation

- 1) How do **urban settlements** impact **protected areas** at global and regional scales?
- 2) How will this relationship change as cities **expand** throughout the century?

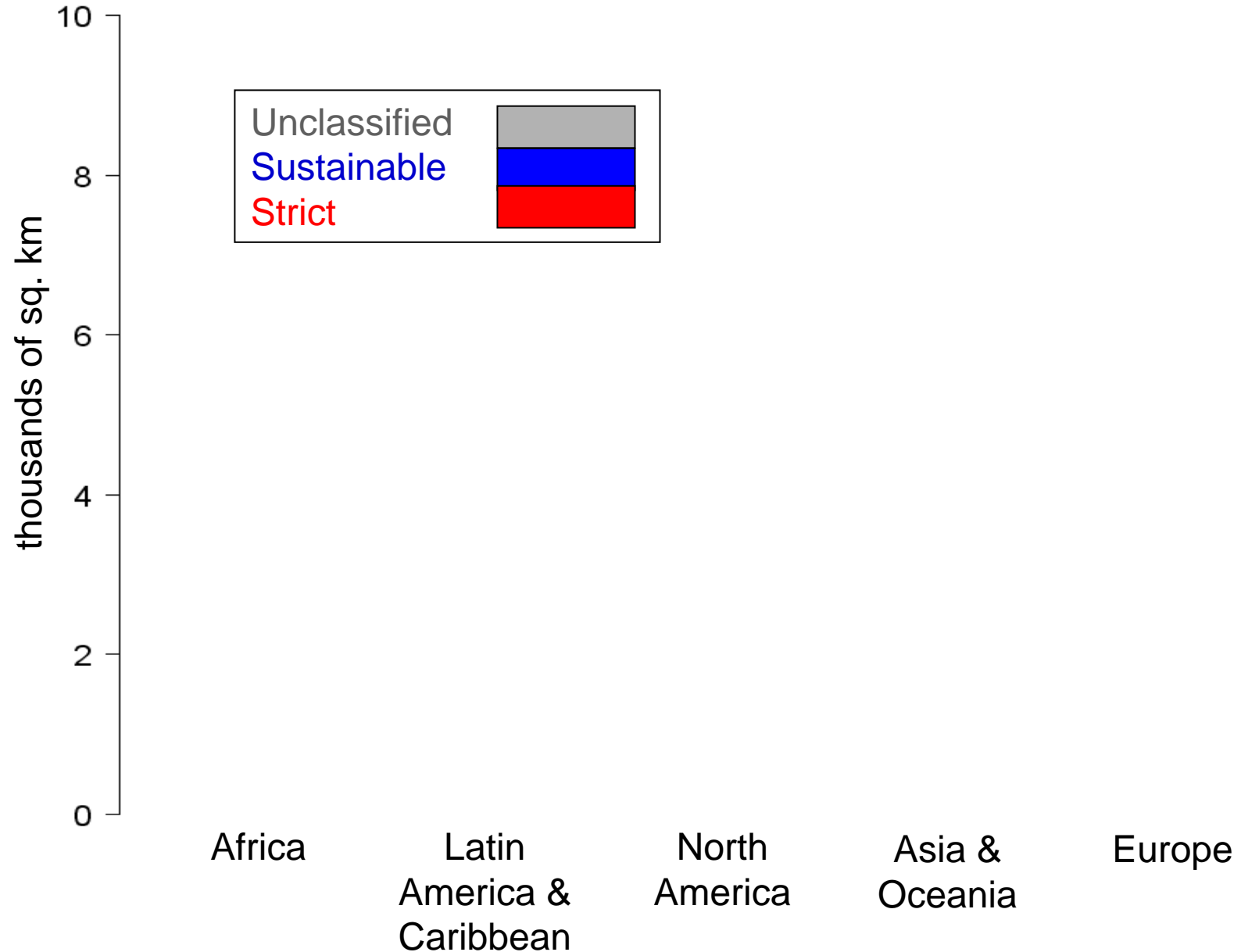


	Unprotected	(121)		Unclassified	(3.8)
				Sustainable	(5.5)
				Strict	(7.6)

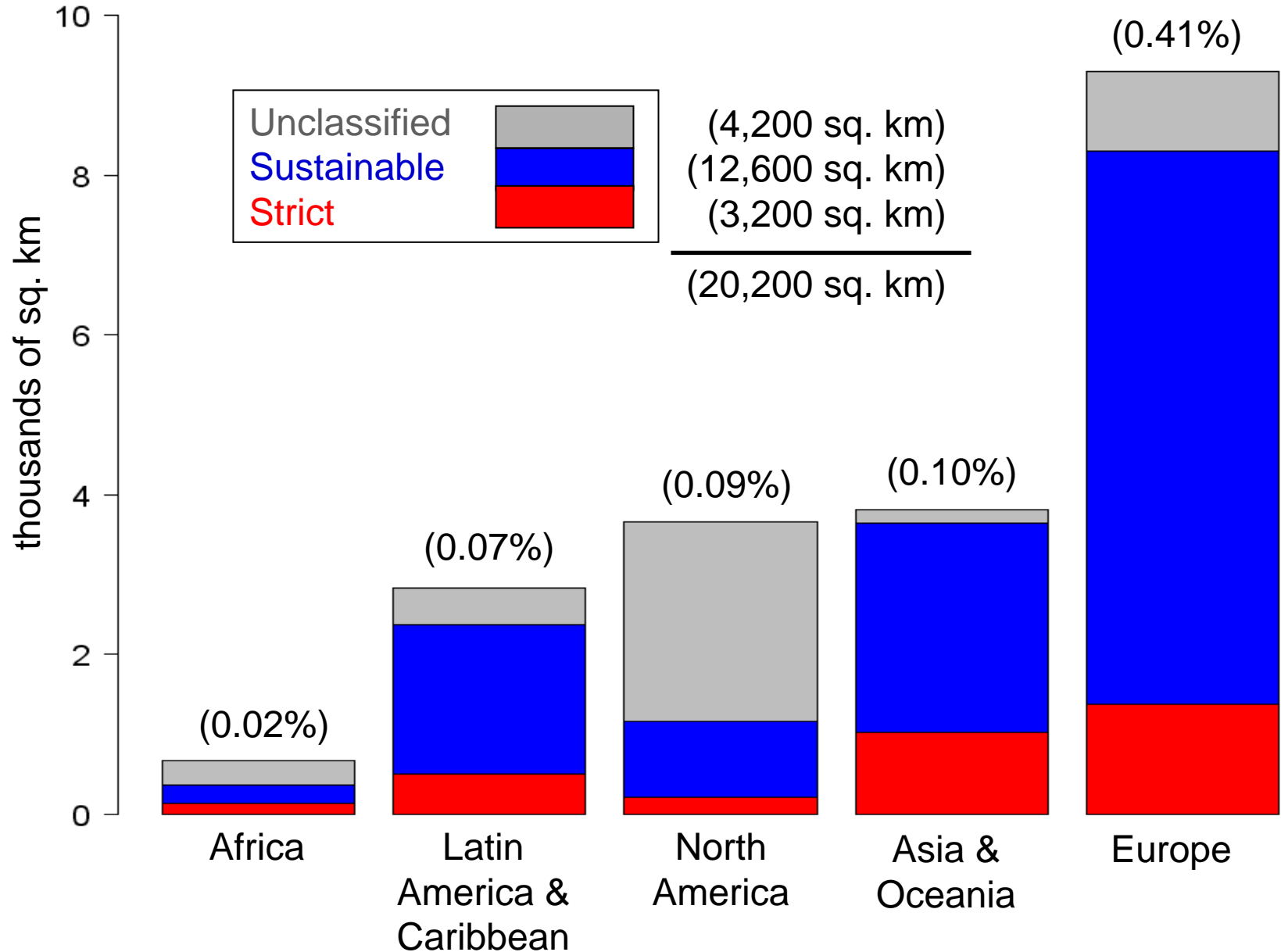
World Database of Protected Areas 2007



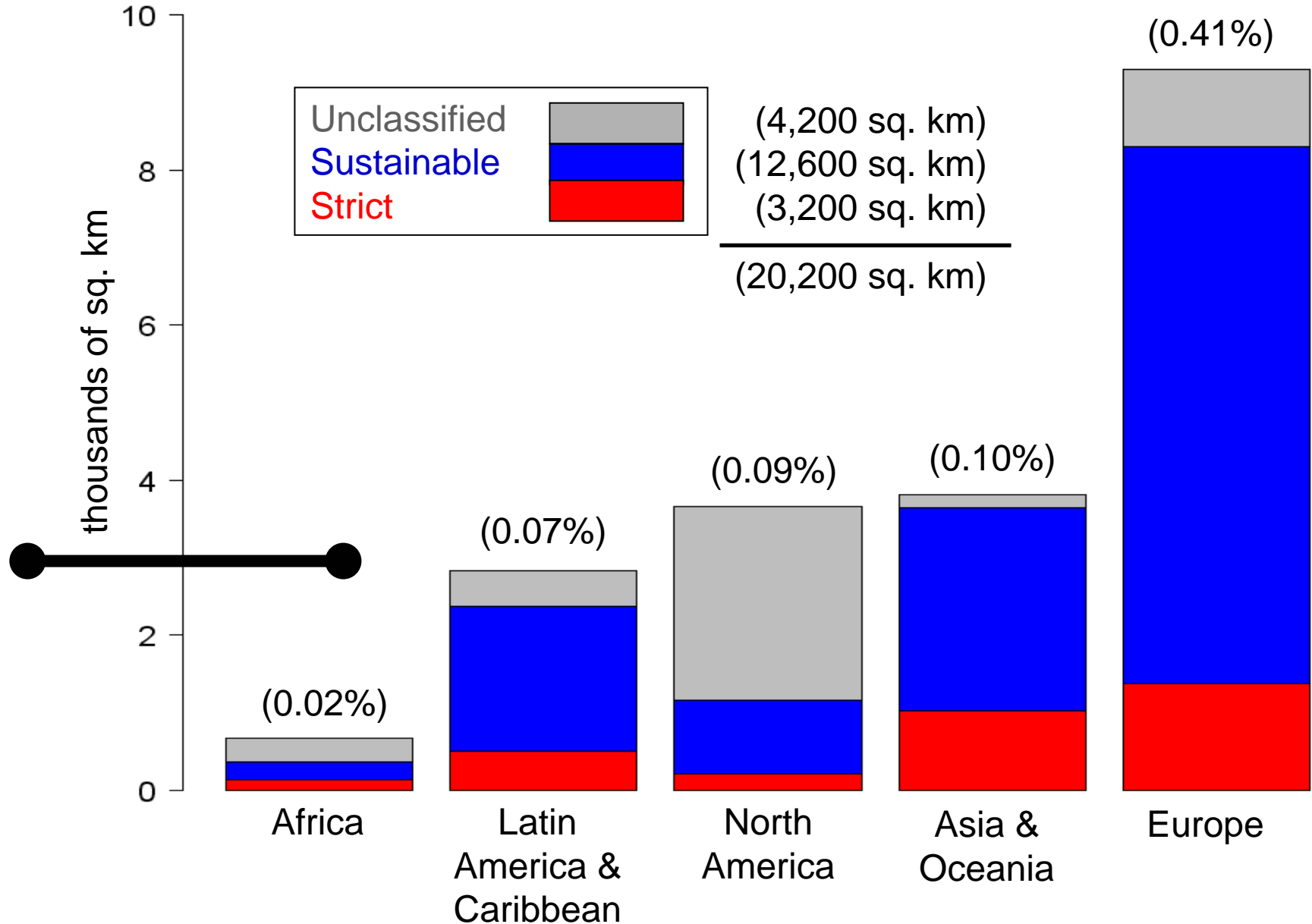
Overlaps : urban inholdings and incursions



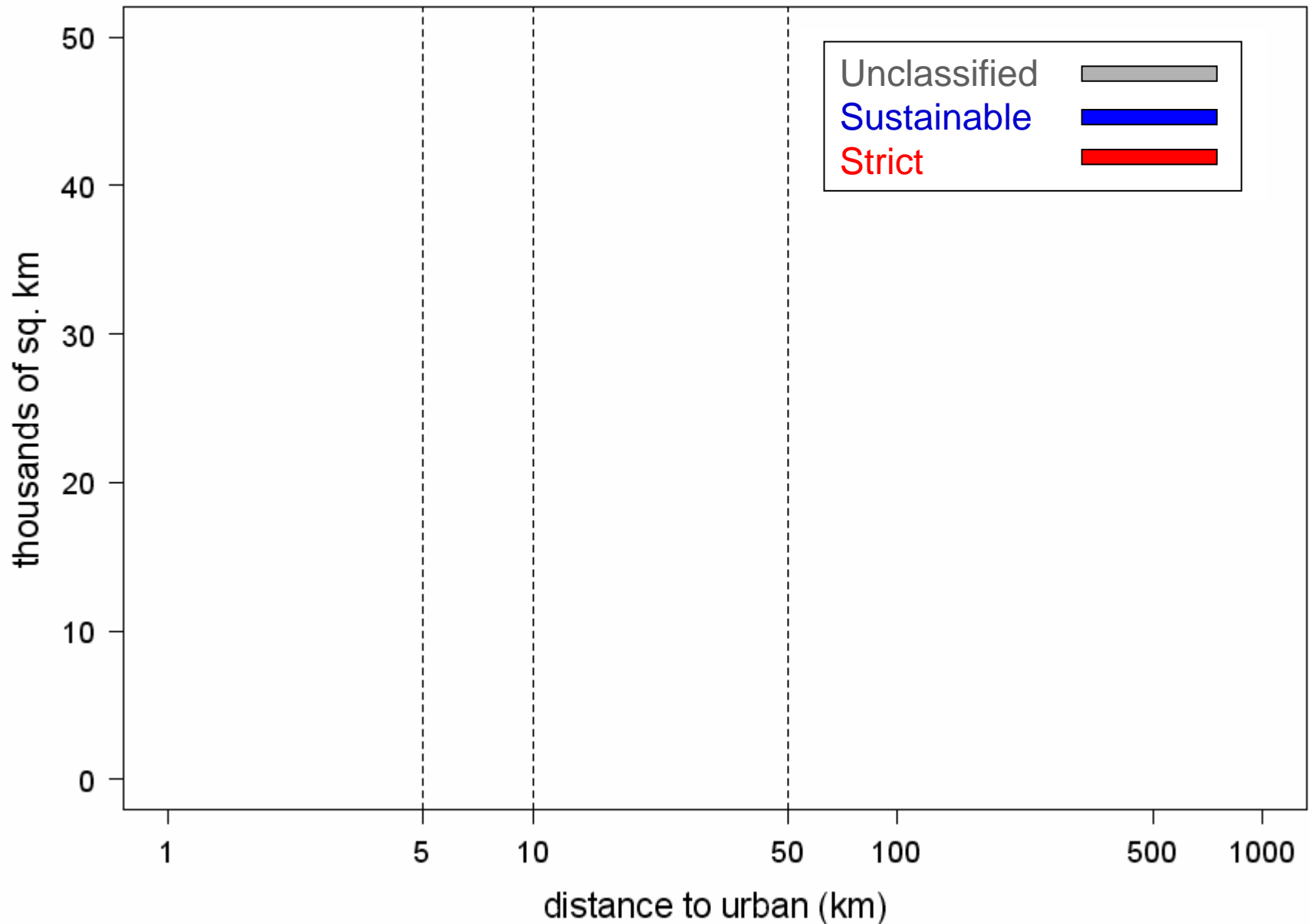
Overlaps : urban inholdings and incursions



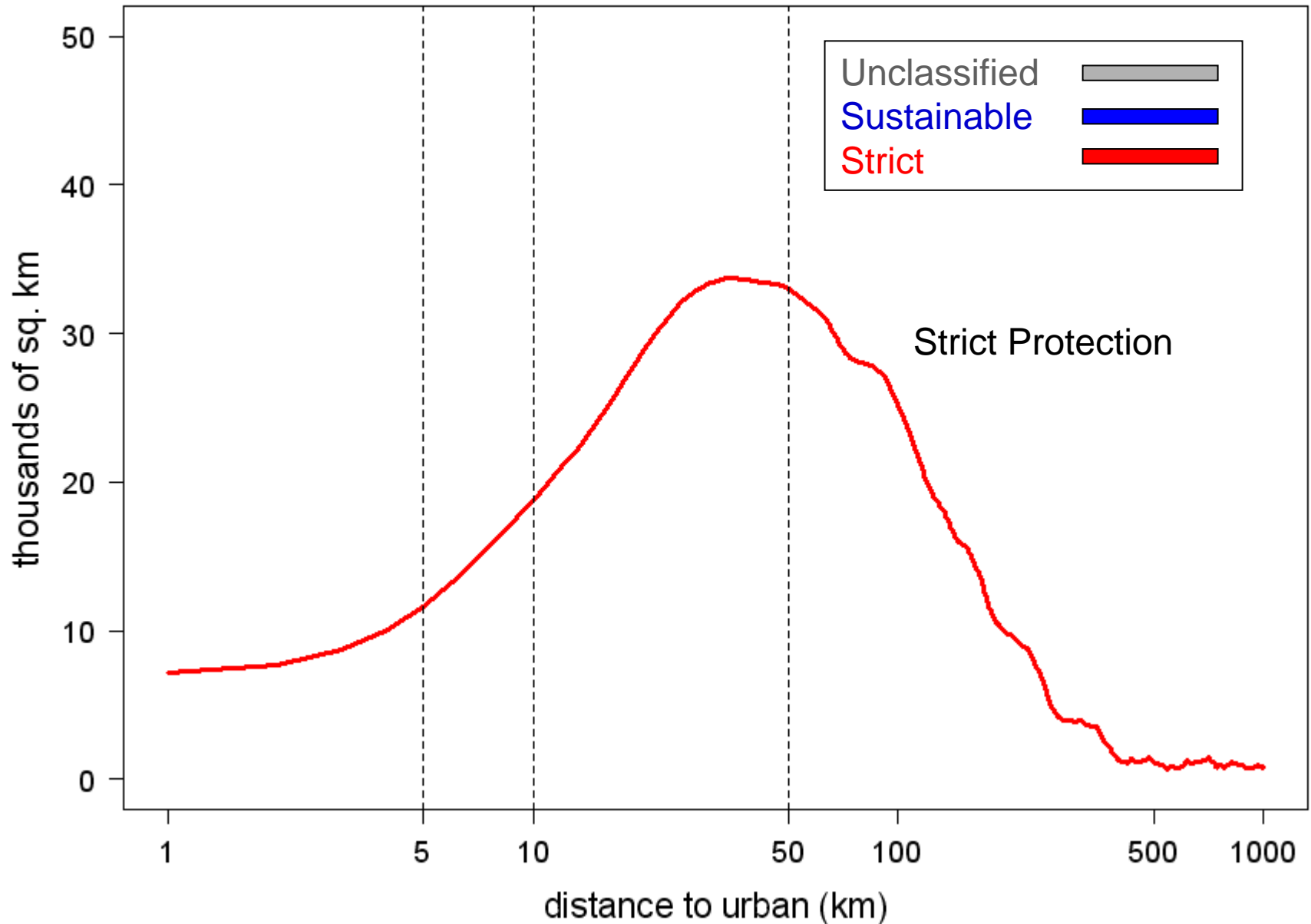
Overlaps : urban inholdings and incursions



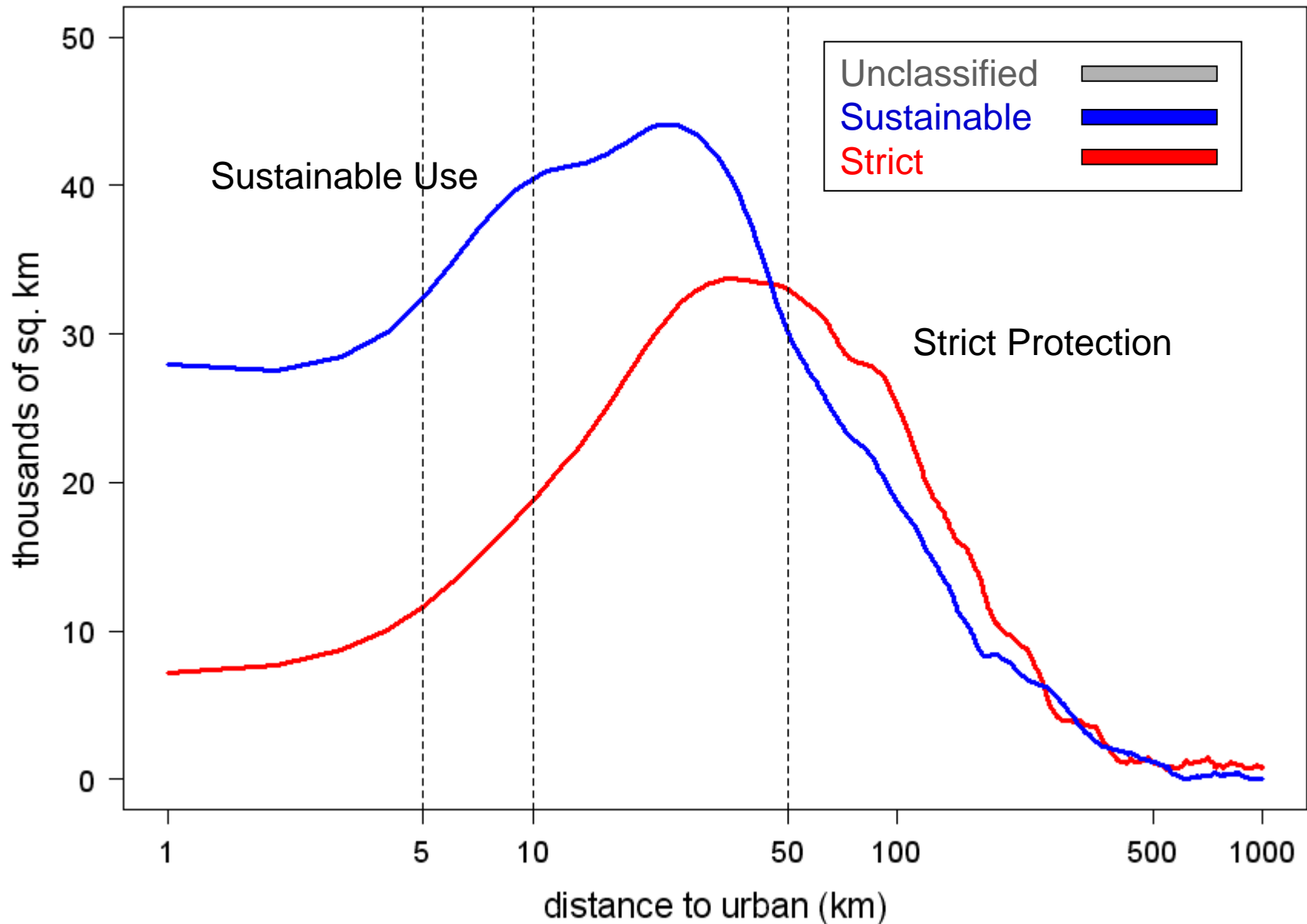
Proximity of protected areas to MOD500



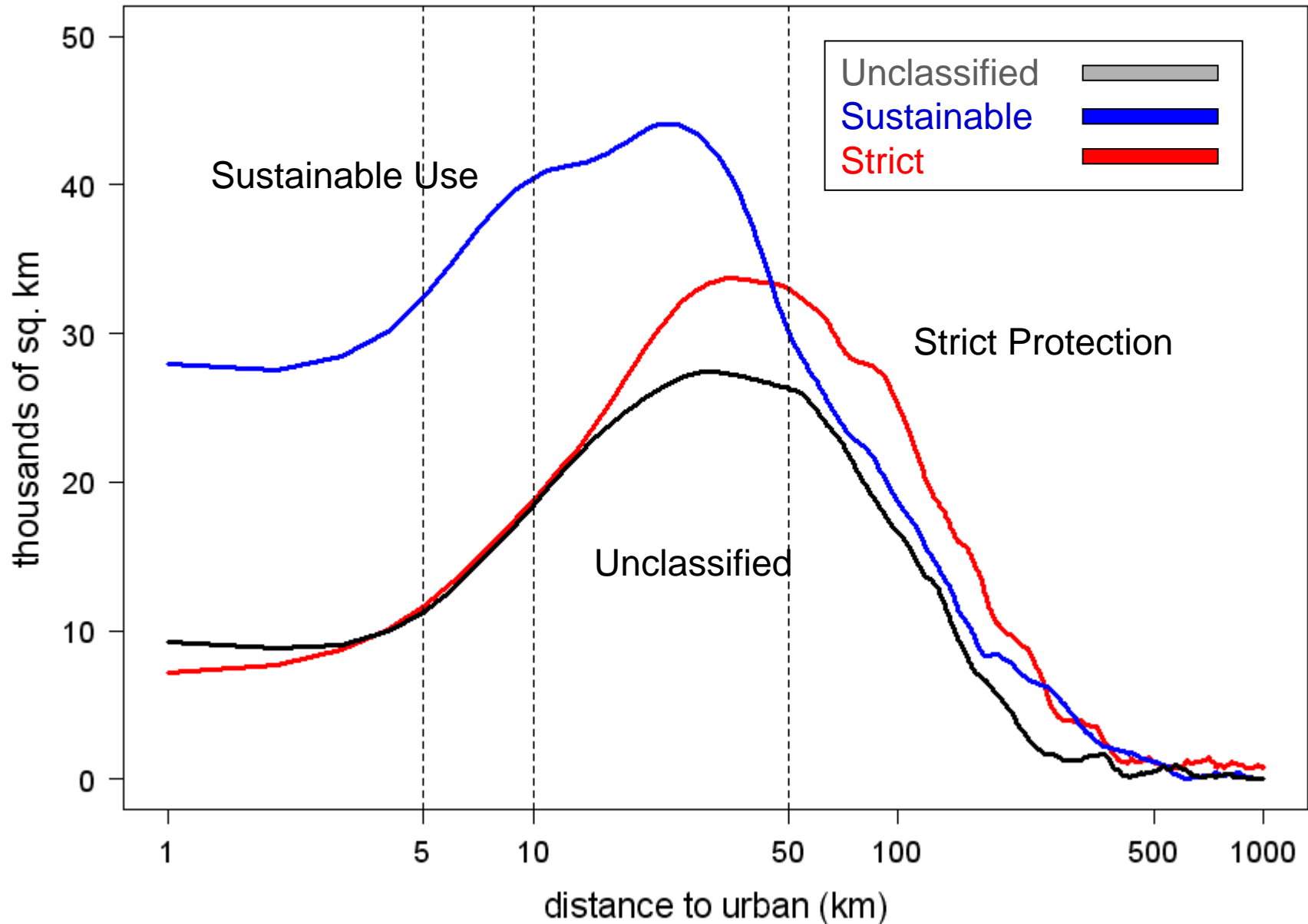
Proximity of protected areas to MOD500



Proximity of protected areas to MOD500



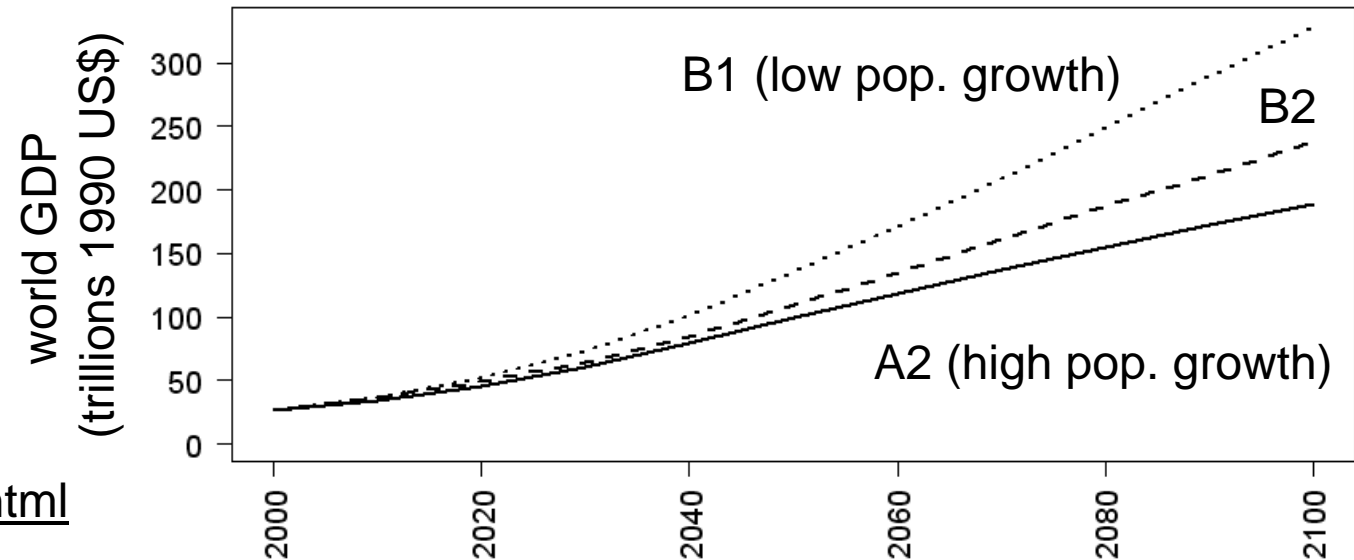
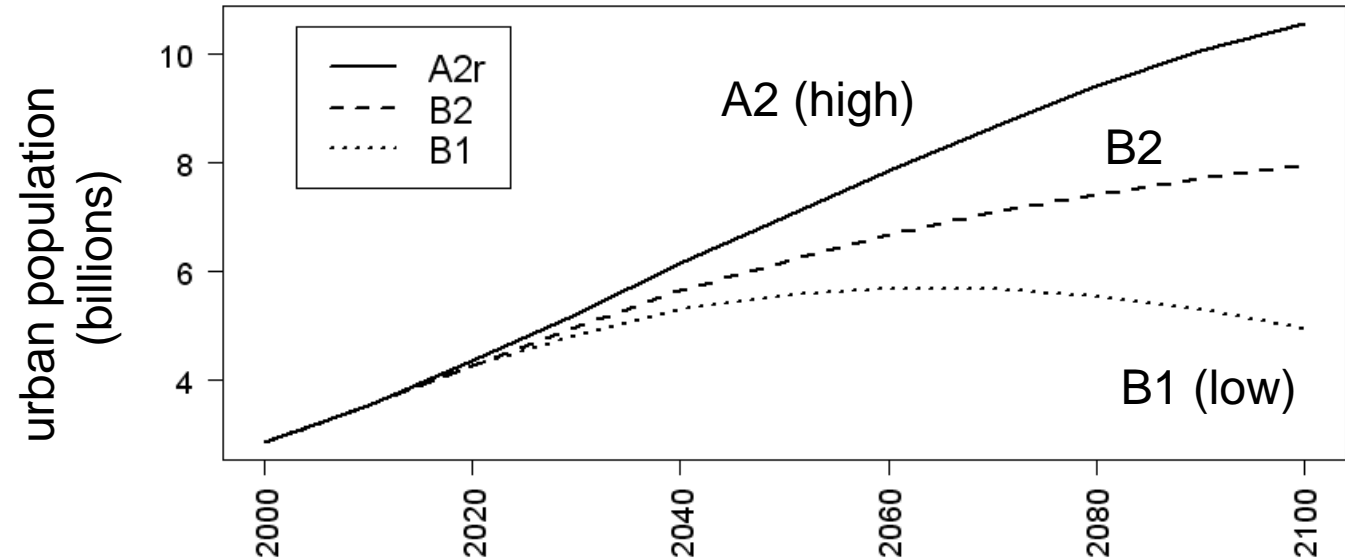
Proximity of protected areas to MOD500



Modeling urban expansion

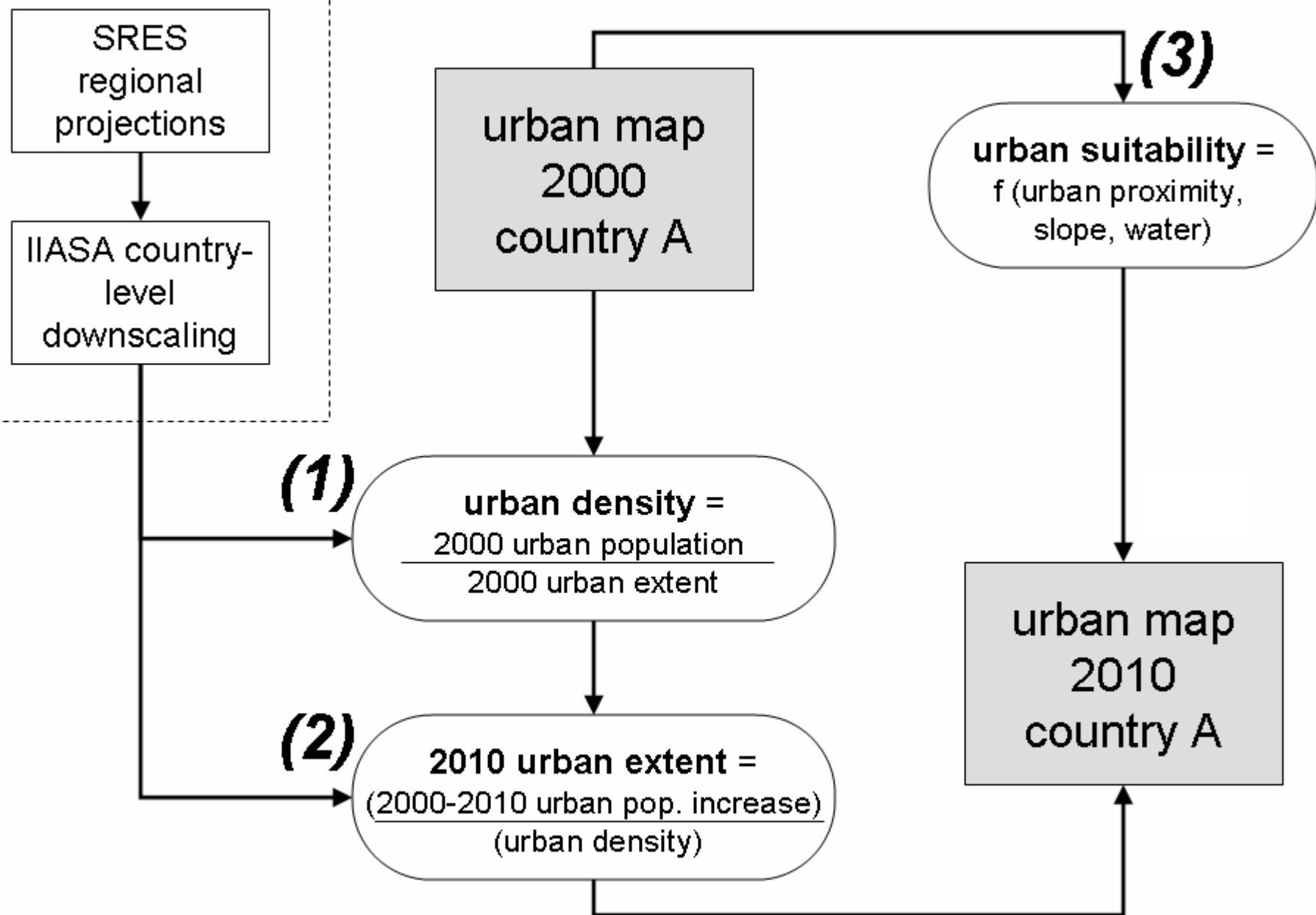
- Simple, both conceptually and computationally
- Embraces a wide range of demographic and economic futures
- Global in scope, medium spatial resolution, decadal time-steps

IPCC-Special Report on Emissions Scenarios (SRES), Storylines updates and modified by IIASA

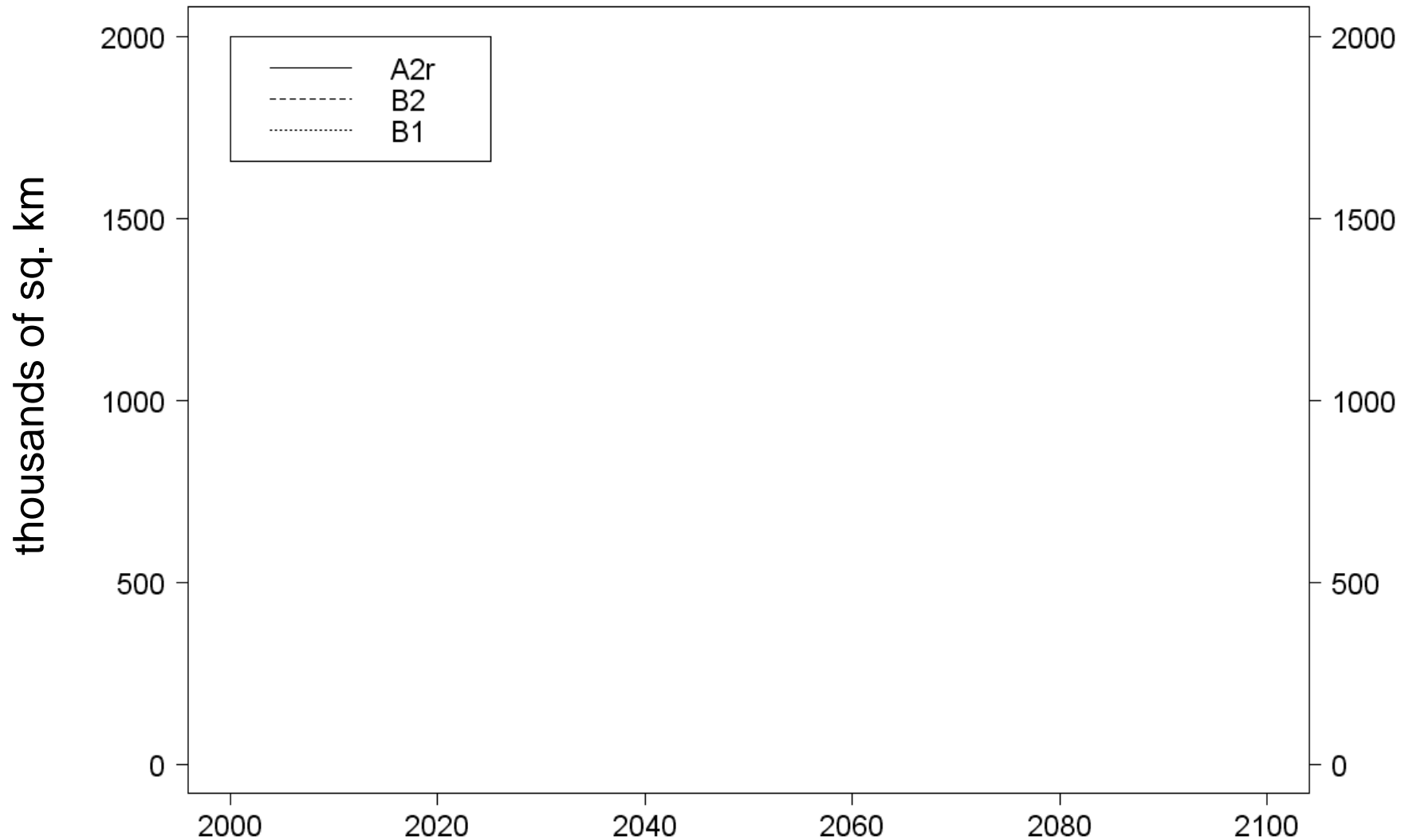


Grubler et al.
(2007)

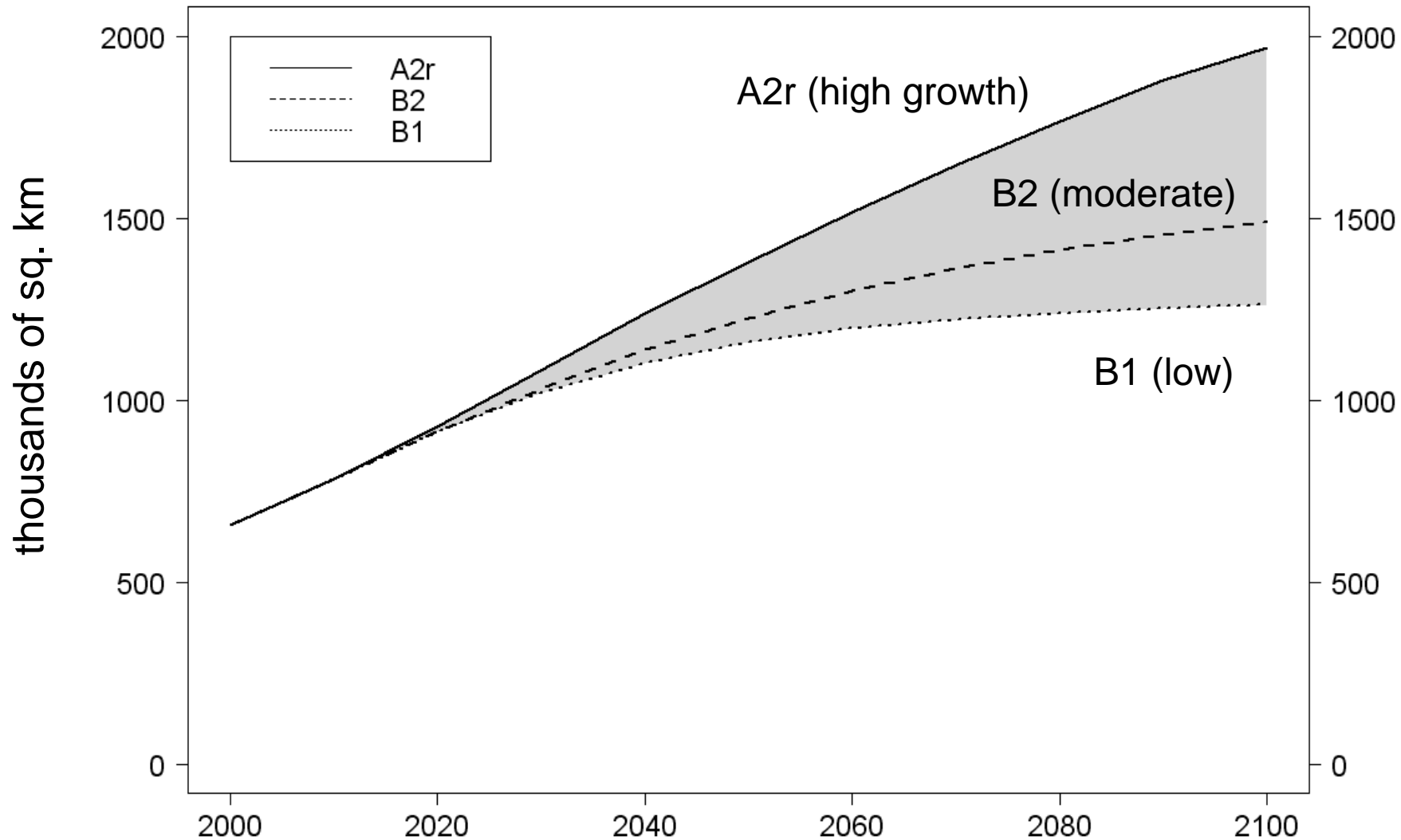
[http://www.iiasa.ac.at/
Research/GGI/index.html](http://www.iiasa.ac.at/Research/GGI/index.html)



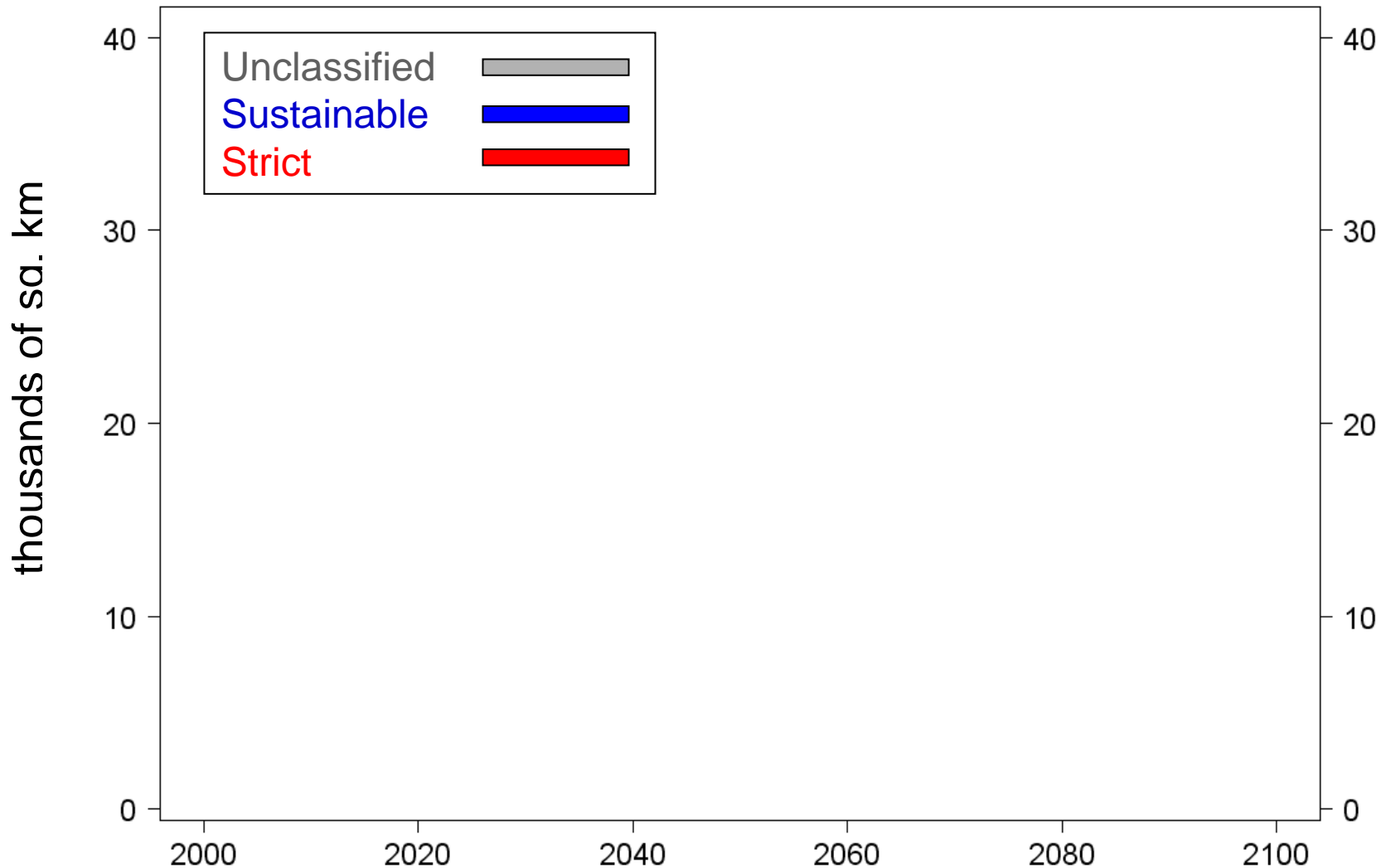
Urban area 2000-2100, three storylines



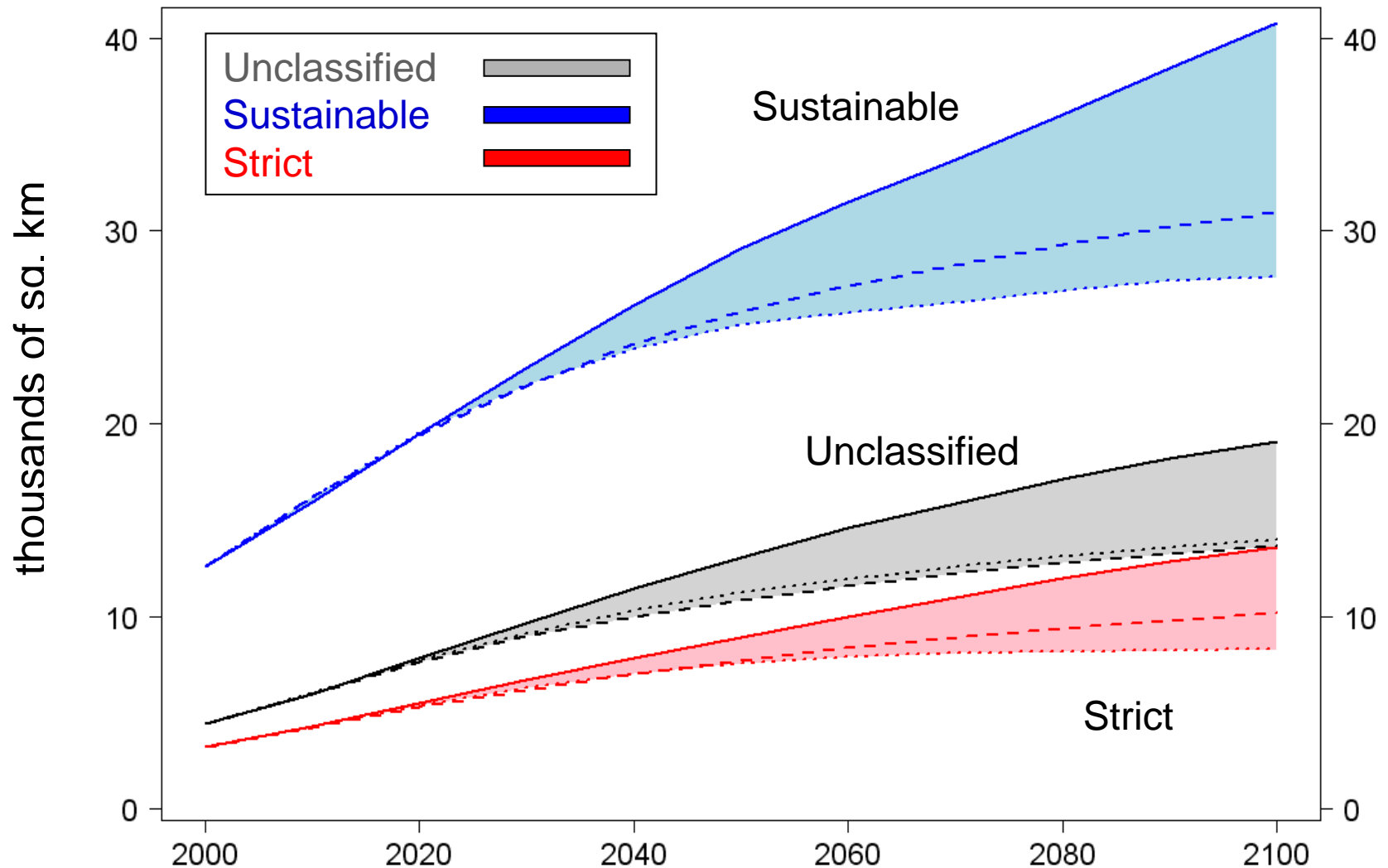
Urban area 2000-2100, three storylines



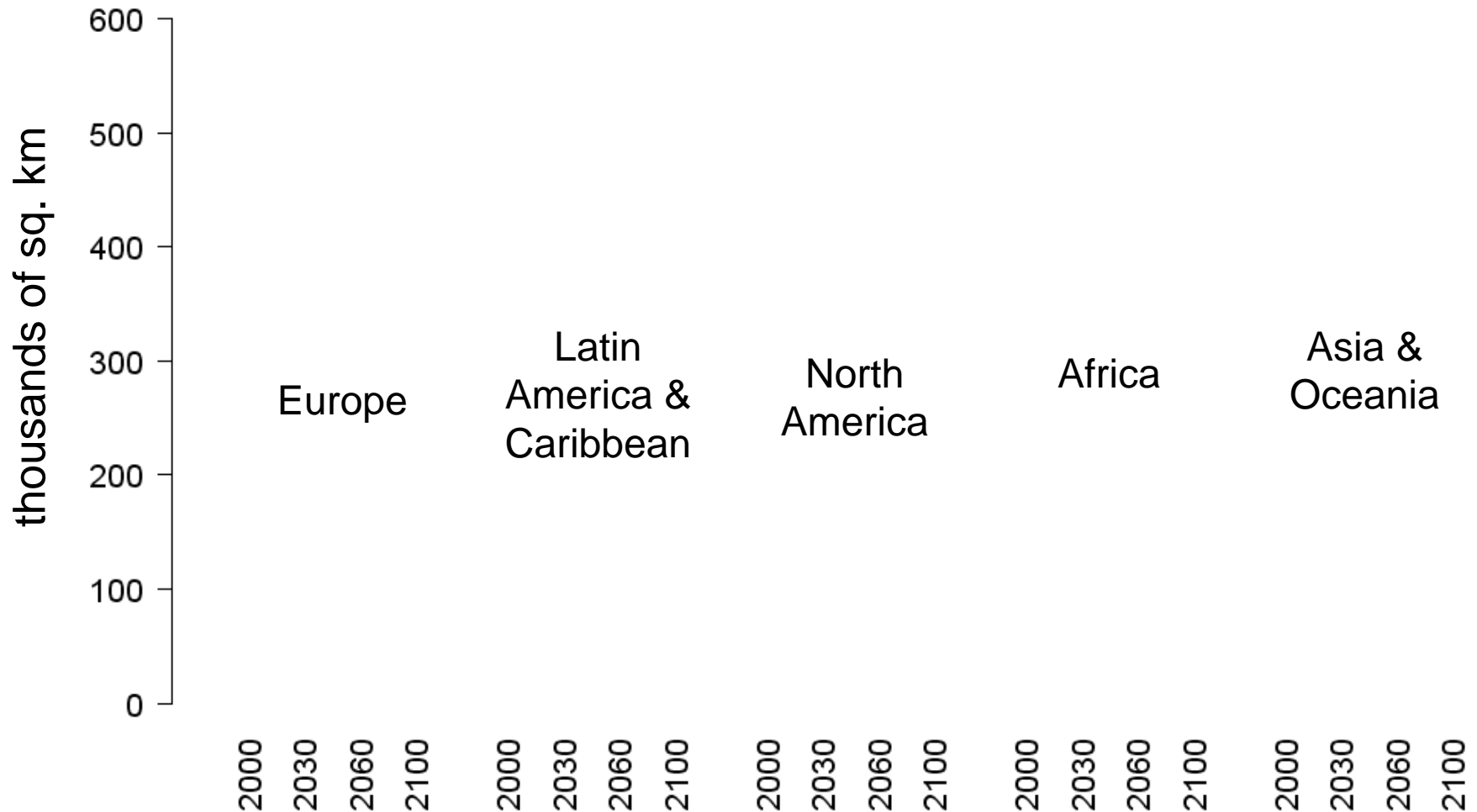
Cumulative protected area 'losses' 2000-2100, three storylines



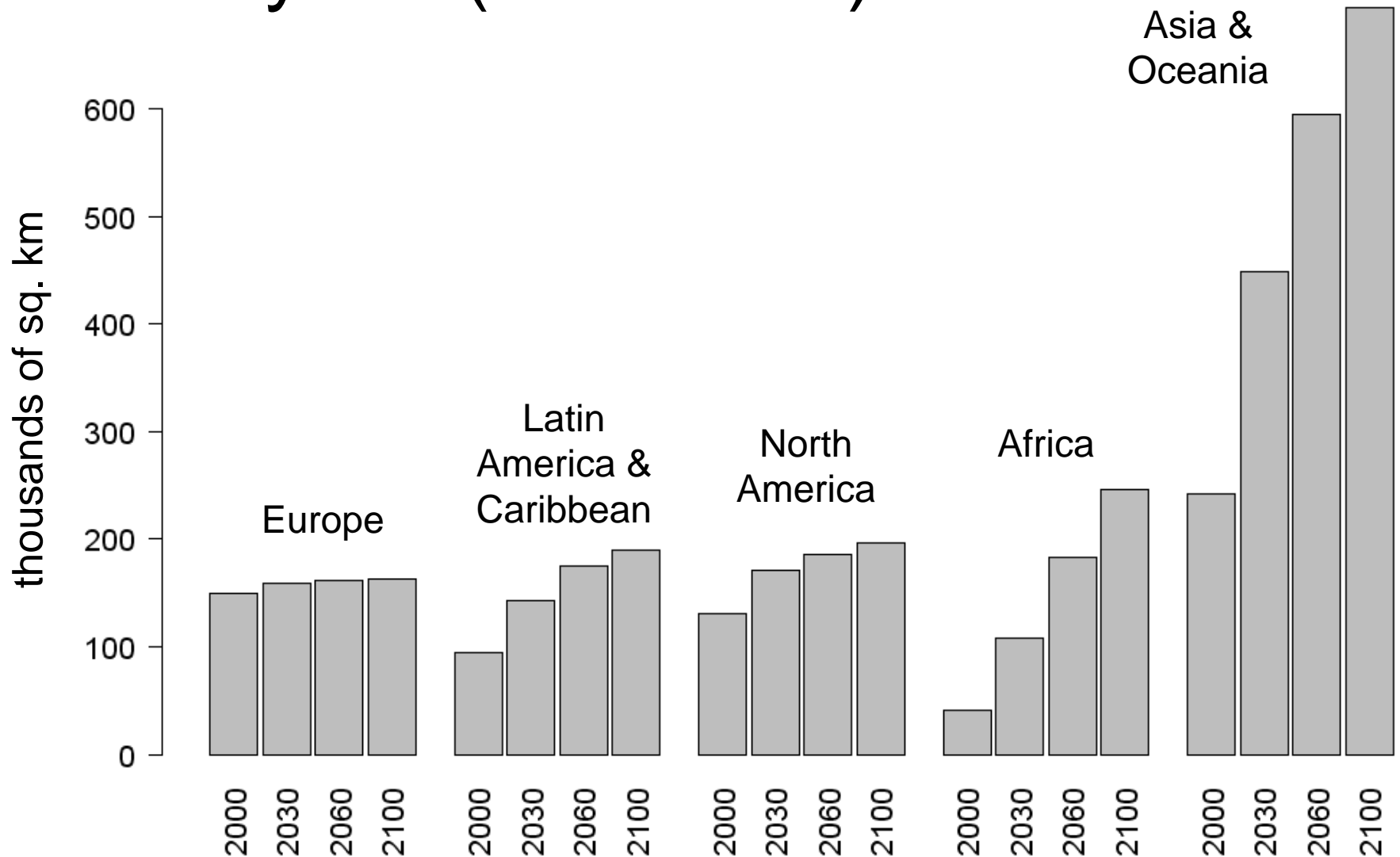
Cumulative protected area 'losses' 2000-2100, three storylines



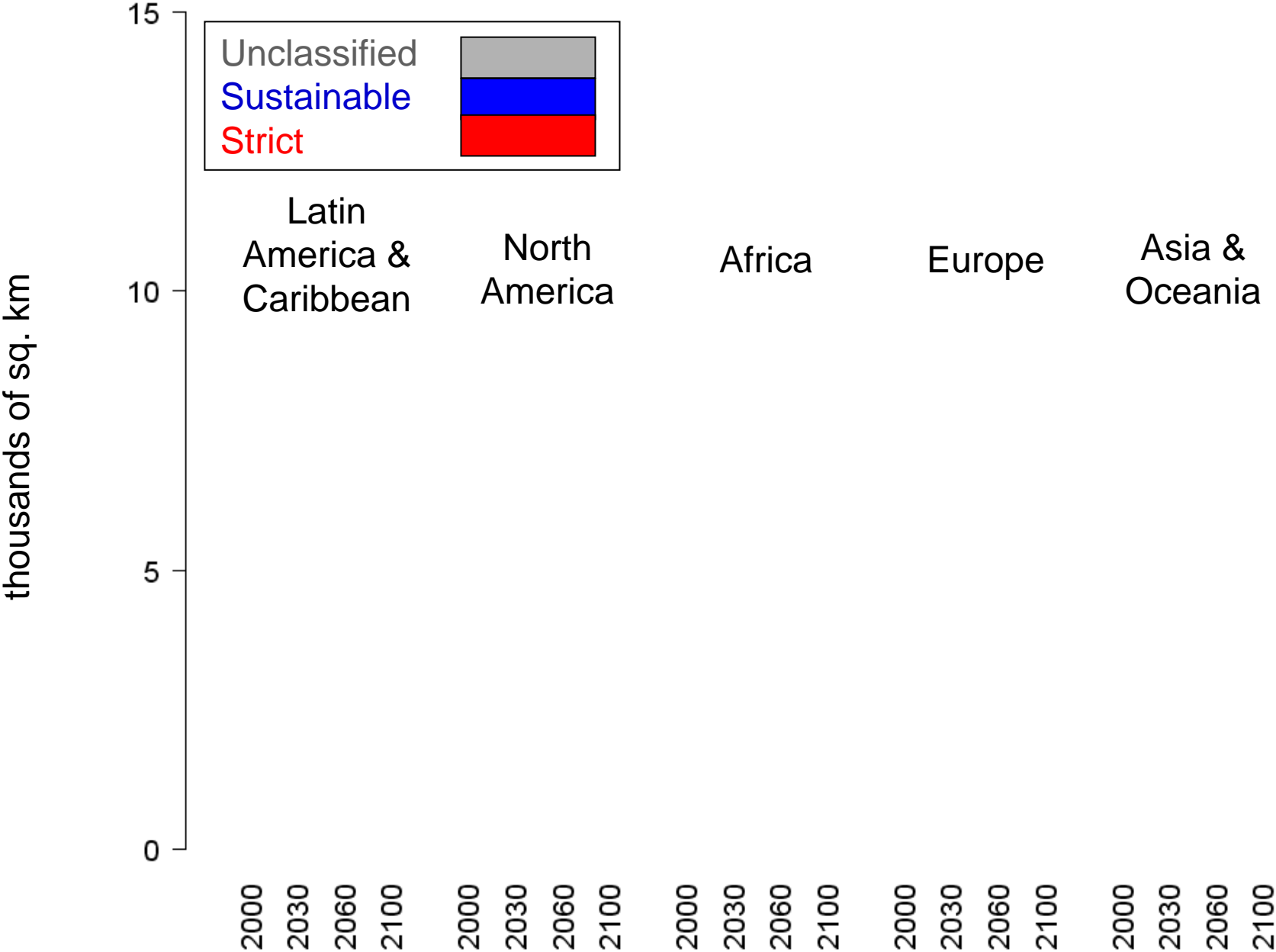
Urban area 2000-2100, B2 storyline (moderate)



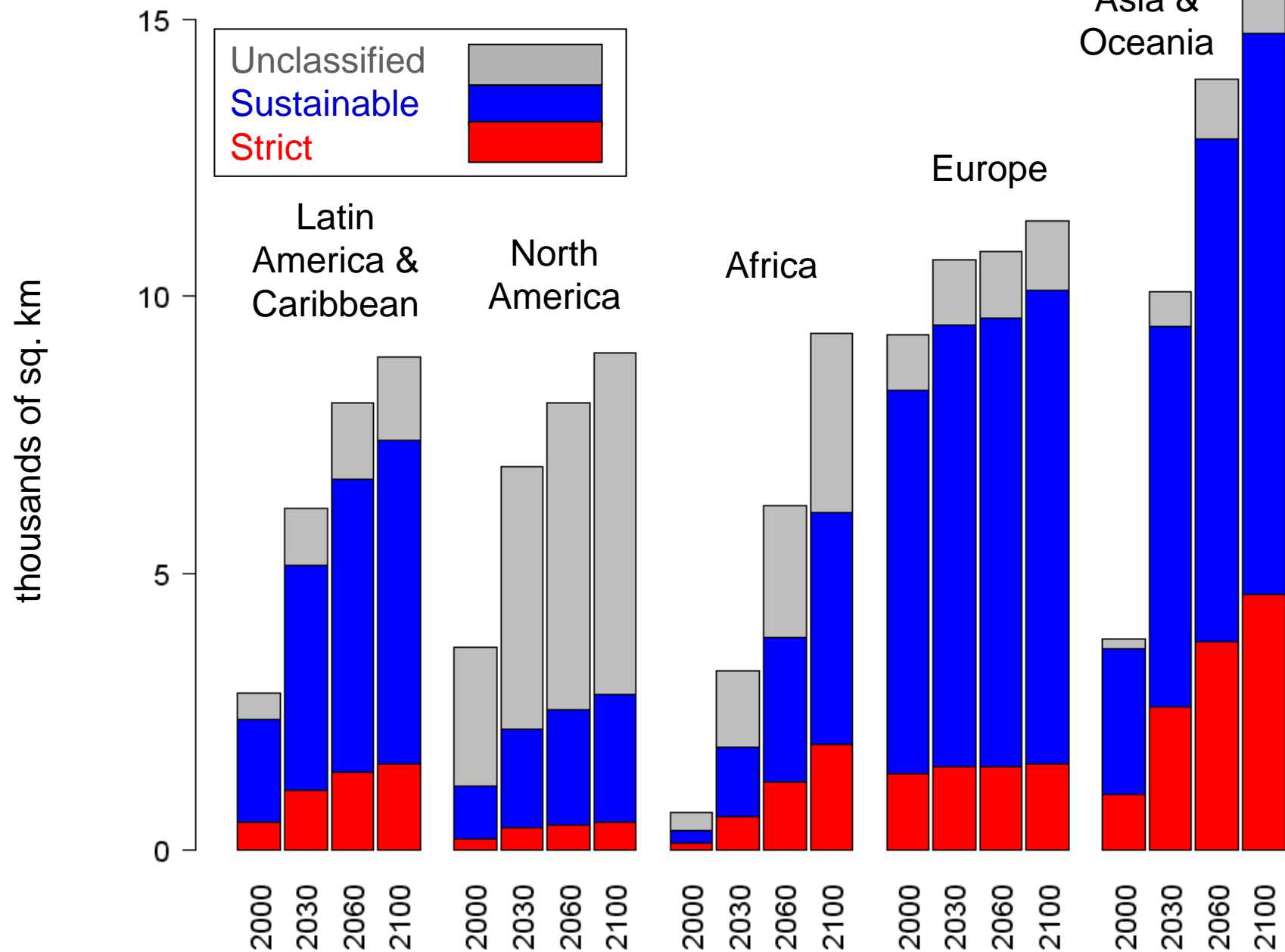
Urban area 2000-2100, B2 storyline (moderate)



Protected area losses, B2 (mod.)



Protected area losses, B2 (mod.)



Main Findings

- MODIS 500m is the most appropriate map for conservation applications.
- 20,000+ sq. km of inholdings or incursions in protected areas globally as of 2000, mostly in Europe.
- Urban area may triple by 2100 to nearly 2 million sq km, with the bulk of that increase in Africa & Asia.
- 50,000+ additional sq. km of urban land may encroach on protected areas through 2100, most in Africa & Asia.

Future Directions

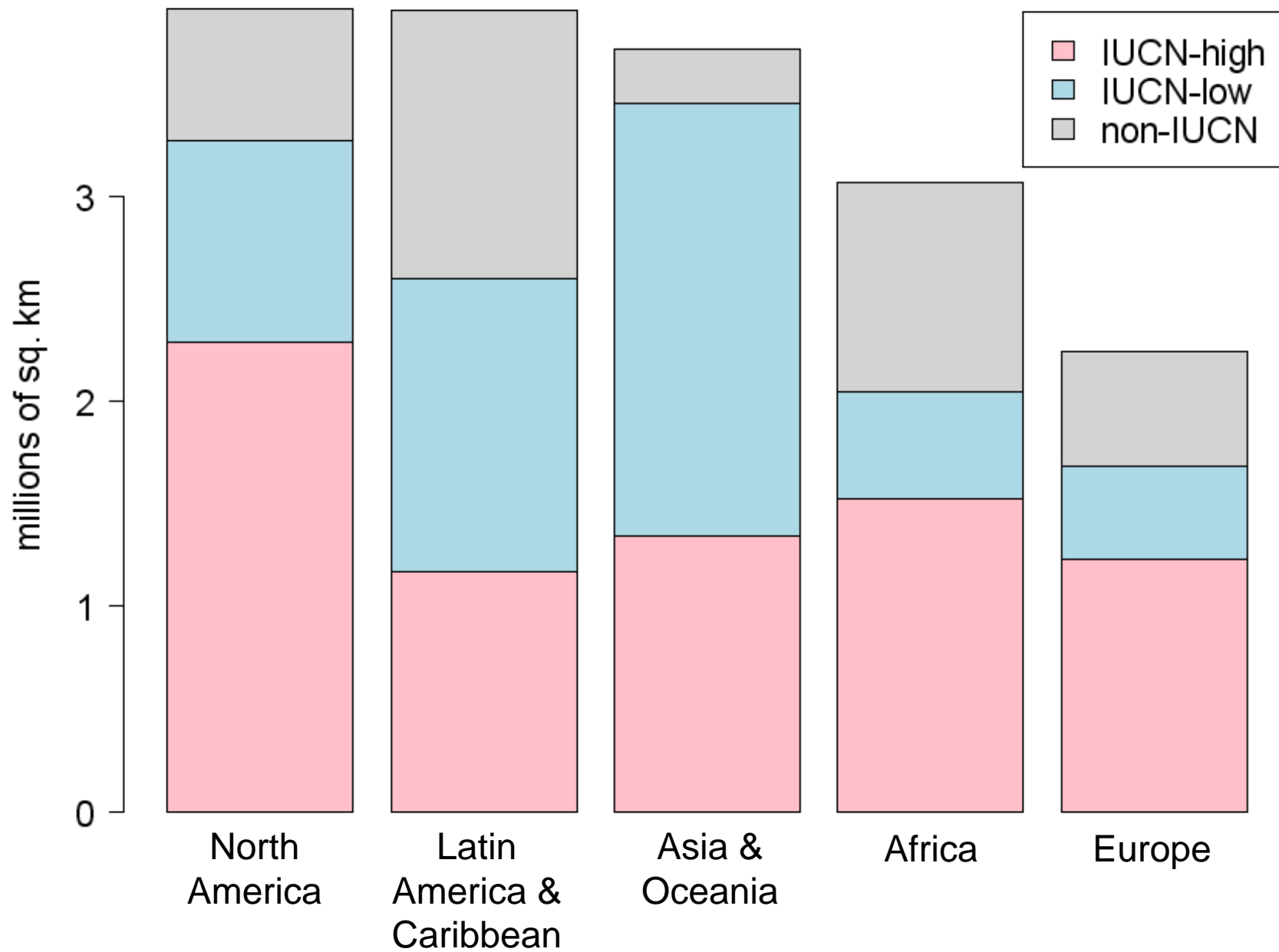
- Map fusion vs. map selection

Future Directions

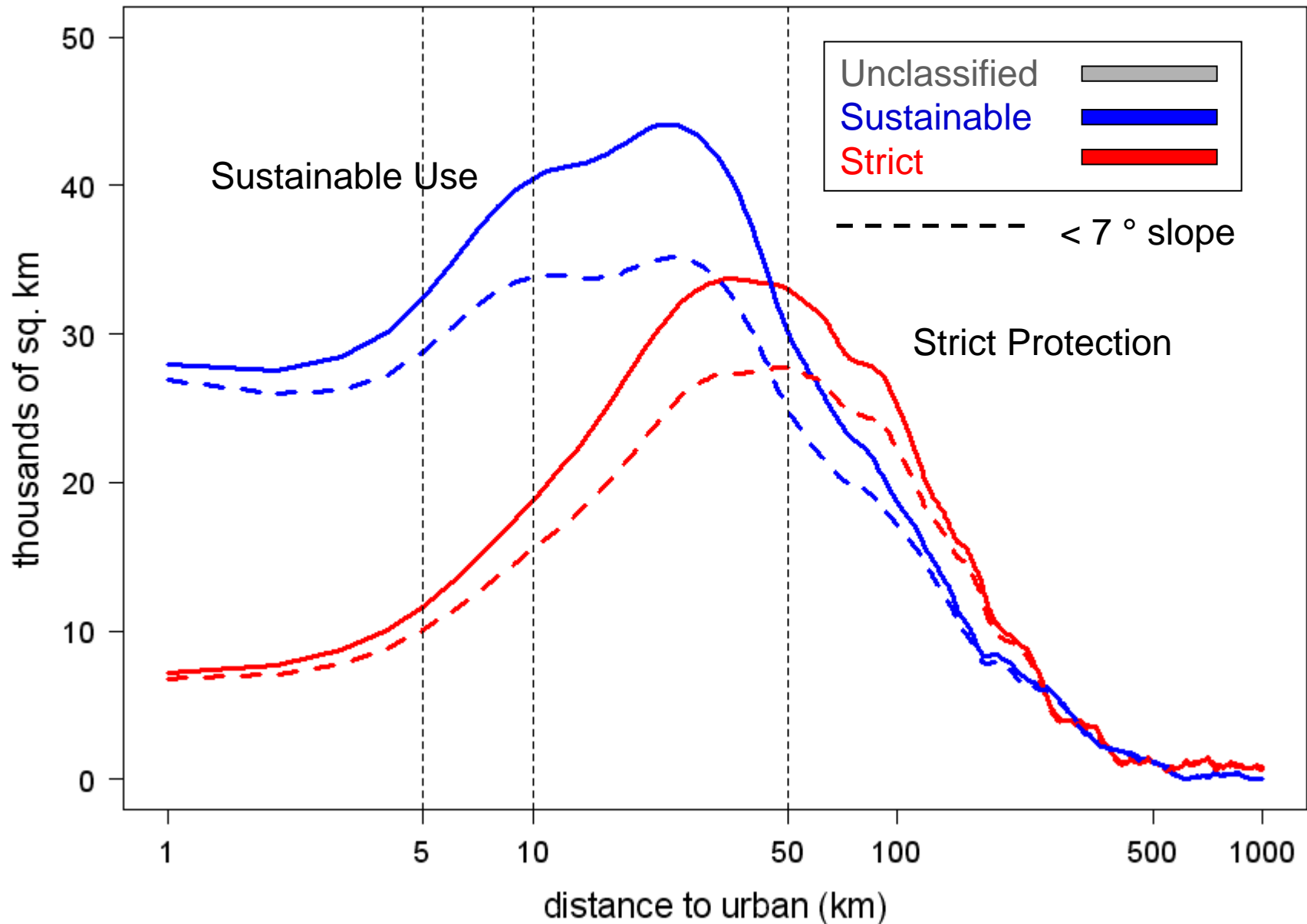
- Map fusion vs. map selection
- Assess the urban inholdings and incursions

Future Directions

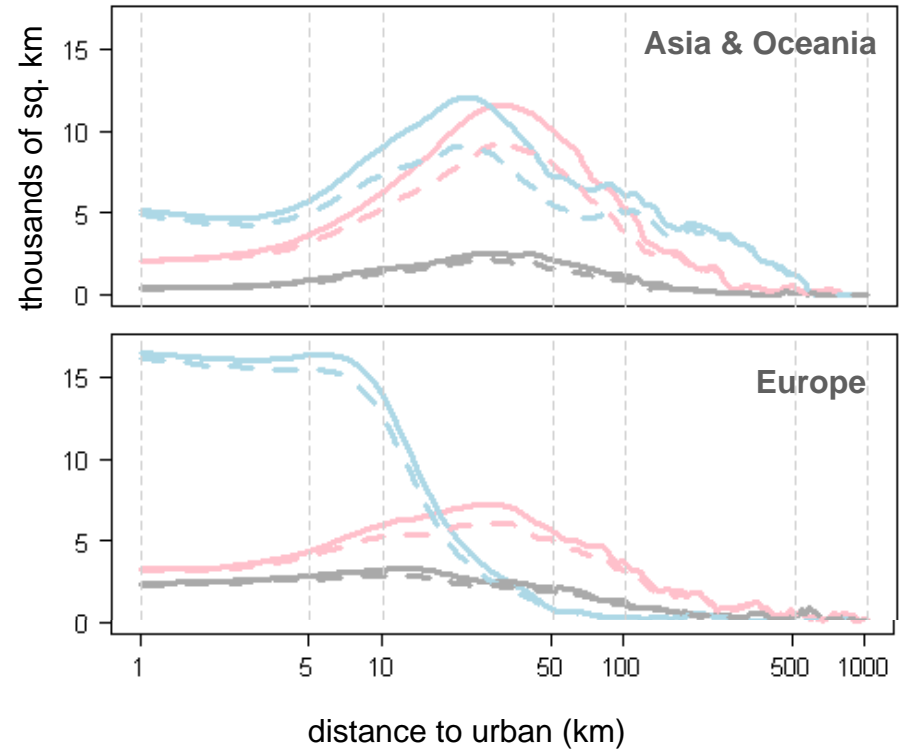
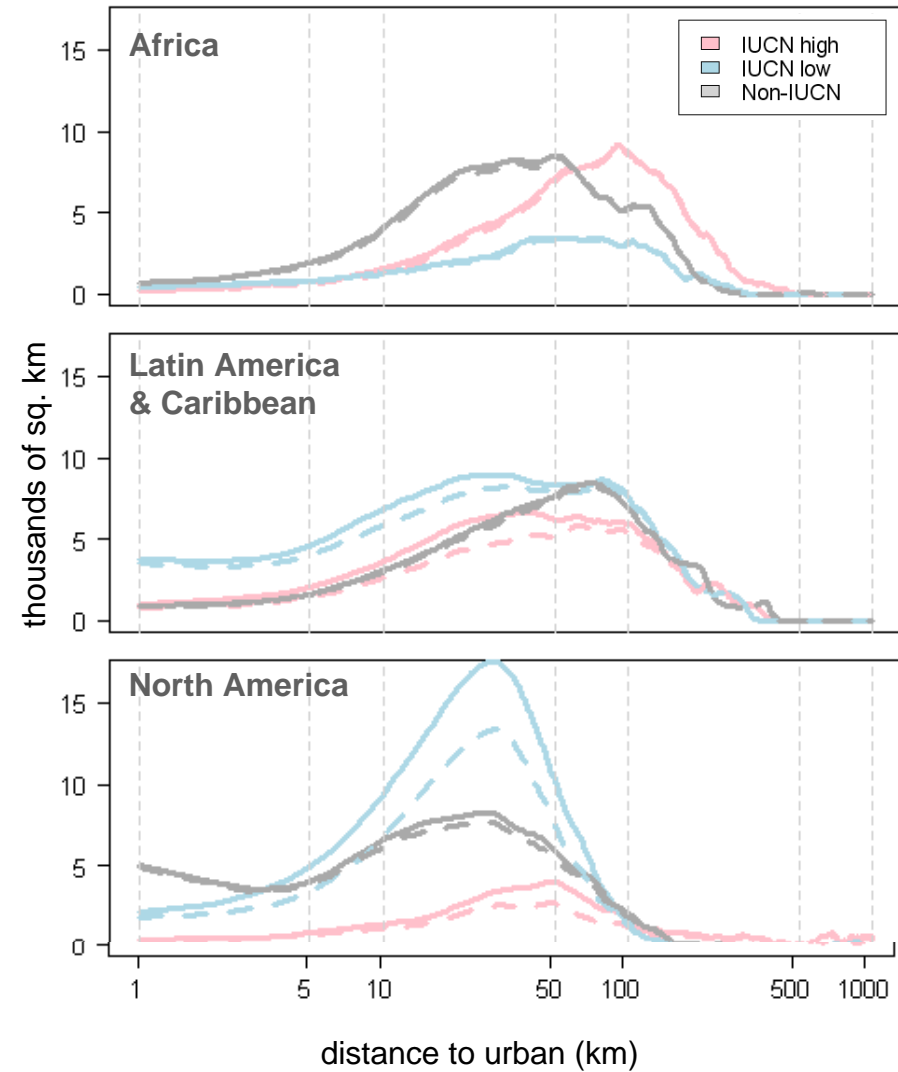
- Map fusion vs. map selection
- Assess the urban inholdings and incursions
- Improve the urban expansion model
 - Model urban density with GDP
 - Improve spatial allocation algorithm
 - Assess model output using Landsat maps
 - Allow protected areas to 'resist' incursion



Proximity of protected areas to MOD500



Regional urban proximities





Sao Paulo, Brazil



San Salvador, El Salvador



Kampala,
Uganda



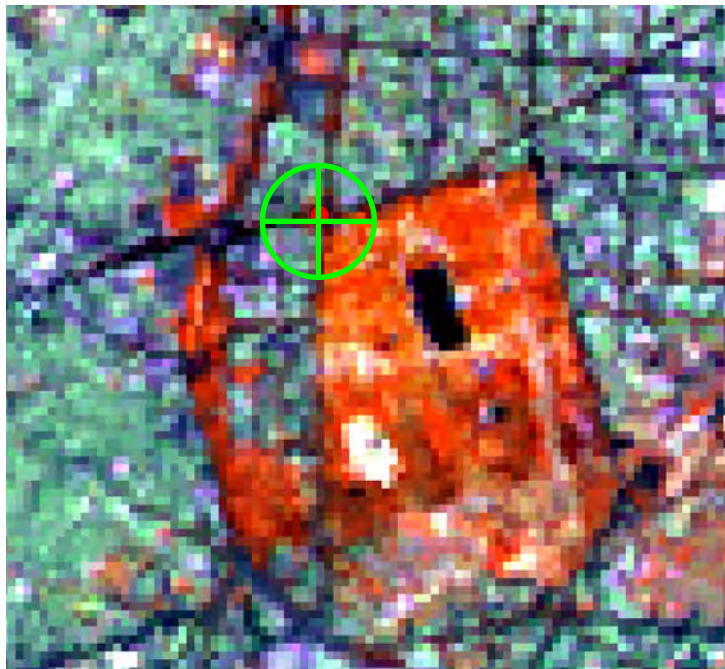
Sao Paulo, Brazil



San Salvador, El Salvador



Kampala,
Uganda

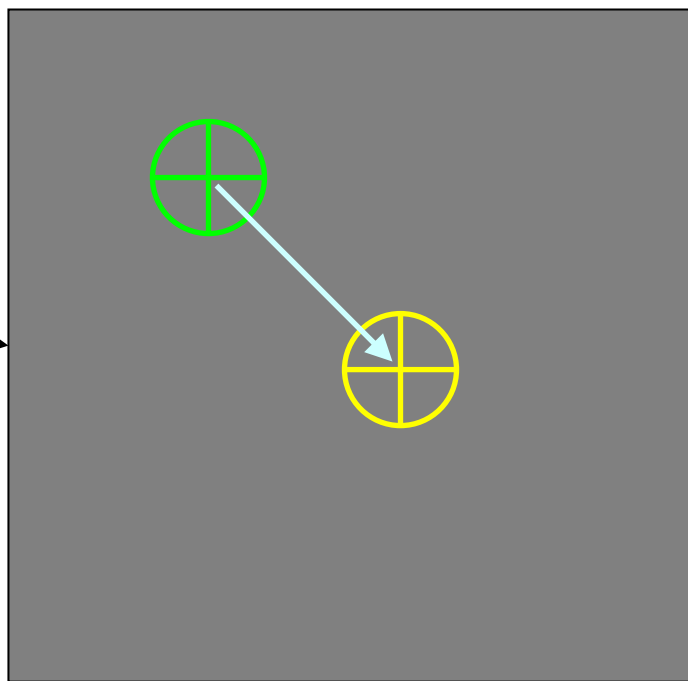


Landsat

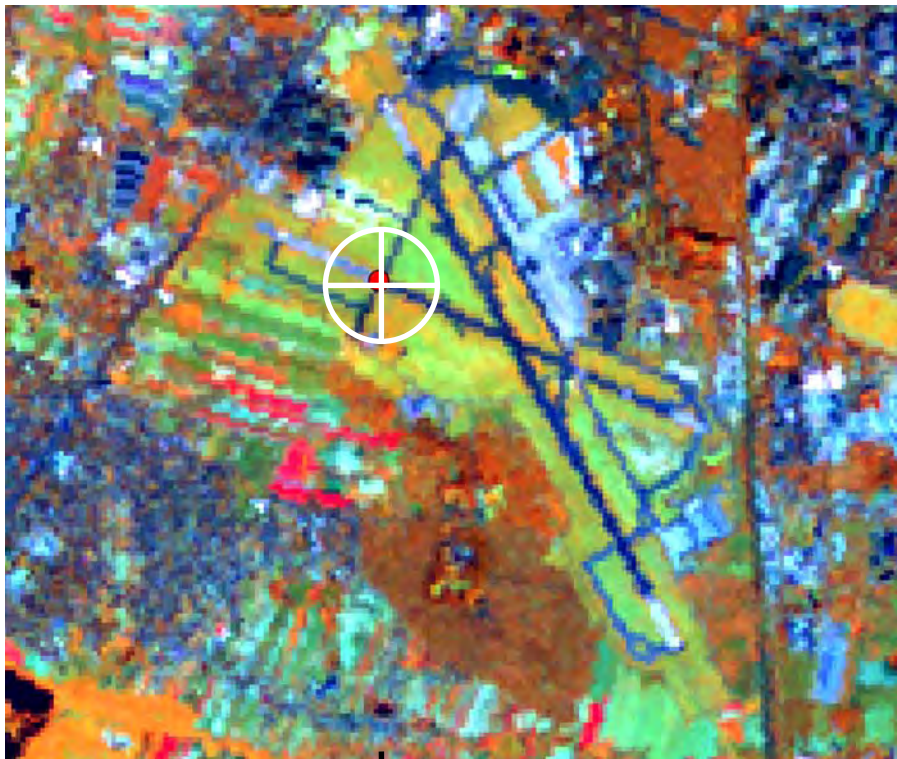


Google

Madrid, Spain



Error Vector (simulated)

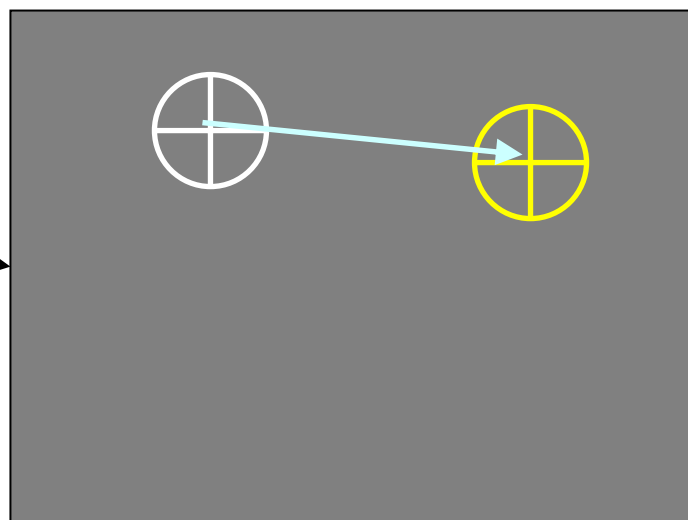


Landsat



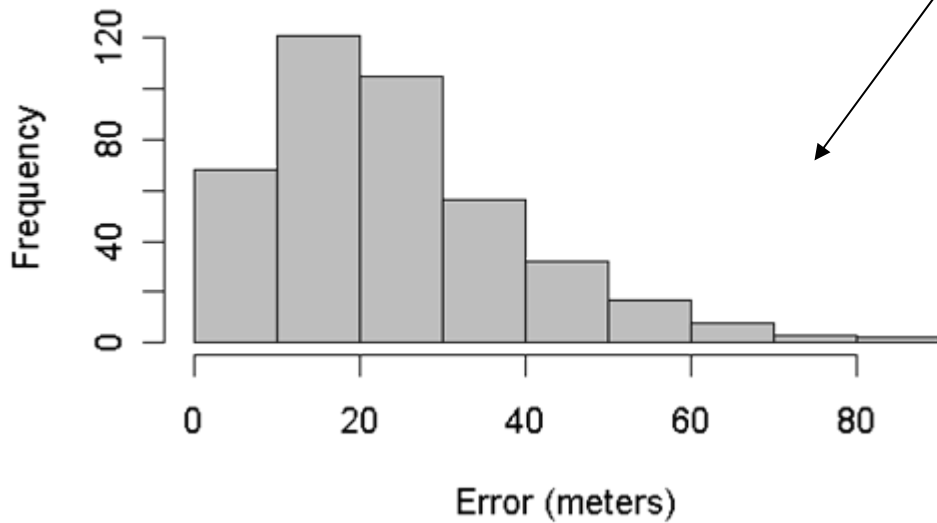
Google

Warsaw, Poland



Error Vector (simulated)

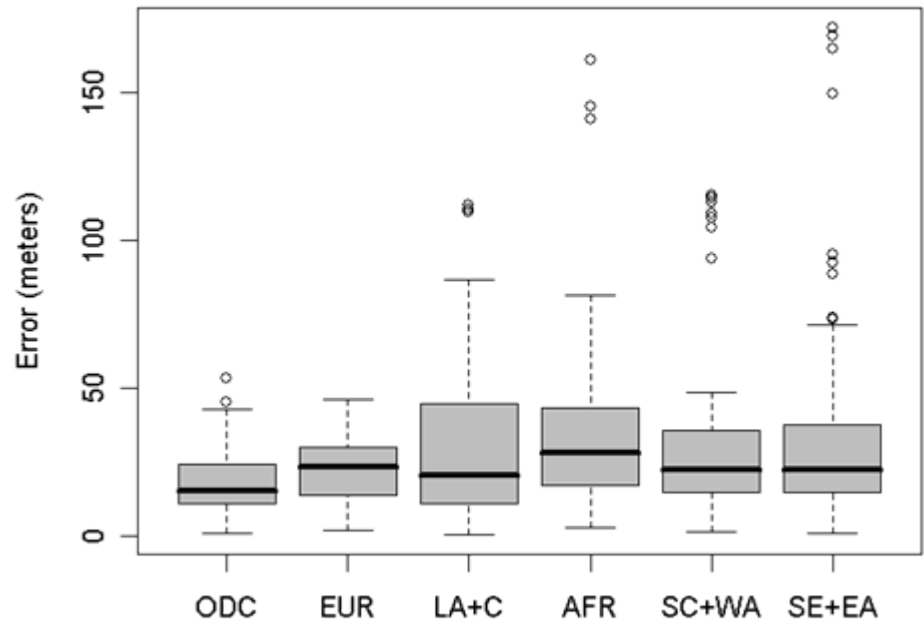
Magnitude of Error Vectors



Mean geodetic error is 29.4 meters (N = 436); accurate enough to validate Landsat.

There are no significant differences in the regional distribution of errors.

Geodetic Errors by Region



Land Cover Validation Project, v 1.0

[Instructions](#)

Please enter user name:

Select City

- | | | | | | |
|---|--|---|--|--|---|
| <input type="radio"/> Accra, Ghana | <input type="radio"/> Addis Ababa, Ethiopia | <input type="radio"/> Ahvaz, Iran | <input type="radio"/> Akashi, Japan | <input type="radio"/> Alexandria, Egypt | <input type="radio"/> Algeirs, Algeria |
| <input type="radio"/> Anging, China | <input type="radio"/> Ansan, Korea | <input type="radio"/> Astrakhan, Russia | <input type="radio"/> Aswan, Egypt | <input type="radio"/> Bacolod, Phillipines | <input type="radio"/> Baku, Azerbaijan |
| <input type="radio"/> Bamako, Mali | <input type="radio"/> Bandung, Indonesia | <input type="radio"/> Bangkok, Thailand | <input type="radio"/> Banjul, Gambia | <input type="radio"/> Beijing, China | <input type="radio"/> Budapest, Hungary |
| <input type="radio"/> Buenos Aires, Argentina | <input type="radio"/> Cairo, Egypt | <input type="radio"/> Caracas, Venezuela | <input type="radio"/> Casablanca, Morocco | <input type="radio"/> Castellon de la Plana, Spain | <input type="radio"/> Cebu, Philippines |
| <input type="radio"/> Changzhi, China | <input type="radio"/> Chicago, United States | <input type="radio"/> Chinju, Korea | <input type="radio"/> Chonan, Korea | <input type="radio"/> Cincinnati, United States | <input type="radio"/> Coimbatore, India |
| <input type="radio"/> Dhaka, Bangladesh | <input type="radio"/> Fukuoka, Japan | <input type="radio"/> Gorgan, Iran | <input type="radio"/> Guadalajara, Mexico | <input type="radio"/> Guangzhou, China | <input type="radio"/> Guaruja, Brazil |
| <input type="radio"/> Guatemala code, Guatemala | <input type="radio"/> Harare, Zimbabwe | <input type="radio"/> Ho Chi Minh code, Vietnam | <input type="radio"/> Hong Kong, China | <input type="radio"/> Houston, United States | <input type="radio"/> Hyderabad, India |
| <input type="radio"/> Ibadan, Nigeria | <input type="radio"/> Iiheus, Brazil | <input type="radio"/> Ipoh, Malaysia | <input type="radio"/> Istanbul, Turkey | <input type="radio"/> Jaipur, India | <input type="radio"/> Jalna, India |
| <input type="radio"/> Jequie, Brazil | <input type="radio"/> Johannesburg, South Africa | <input type="radio"/> Kampala, Uganda | <input type="radio"/> Kanpur, India | <input type="radio"/> Kigali, Rwanda | <input type="radio"/> Kingston, Jamaica |
| <input type="radio"/> Kolkota, India | <input type="radio"/> Kuala Lumpur, Malaysia | <input type="radio"/> Kuwait code, Kuwait | <input type="radio"/> Los Angeles, United States | <input type="radio"/> Leipzig, Germany | <input type="radio"/> Le Mans, France |
| <input type="radio"/> Leshan, China | <input type="radio"/> London, United Kingdom | <input type="radio"/> Madrid, Spain | <input type="radio"/> Malata, Turkey | <input type="radio"/> Manila, Philippines | <input type="radio"/> Marrakech, Morocco |
| <input type="radio"/> Medan, Indonesia | <input type="radio"/> Mexico code, Mexico | <input type="radio"/> Milano, Italy | <input type="radio"/> Minneapolis, United States | <input type="radio"/> Modesto, United States | <input type="radio"/> Montevideo, Uruguay |
| <input type="radio"/> Moscow, Russia | <input type="radio"/> Mumbai, India | <input type="radio"/> Ndola, Zambia | <input type="radio"/> Oktyabrsky, Russia | <input type="radio"/> Ouagadougou, Burkina Faso | <input type="radio"/> Palembang, Indonesia |
| <input type="radio"/> Palermo, Italy | <input type="radio"/> Paris, France | <input type="radio"/> Philadelphia, United States | <input type="radio"/> Pittsburgh, United States | <input type="radio"/> Port Sudan, Sudan | <input type="radio"/> Pretoria, South Africa |
| <input type="radio"/> Puna, India | <input type="radio"/> Pusan, Korea | <input type="radio"/> Rajshahi, Bangladesh | <input type="radio"/> Ribeirao Preto, Brazil | <input type="radio"/> Saidpur, Bangladesh | <input type="radio"/> Sanaa, Yemen |
| <input type="radio"/> San Salvador, El Salvador | <input type="radio"/> Santiago, Chile | <input type="radio"/> Sao Paulo, Brazil | <input type="radio"/> Seoul, Korea | <input type="radio"/> Shanghai, China | <input type="radio"/> Sheffield, United Kingdom |
| <input type="radio"/> Shimkent, Kazakhstan | <input type="radio"/> Singapore, Singapore | <input type="radio"/> Songkhla, Thailand | <input type="radio"/> Springfield, United States | <input type="radio"/> St. Catharines, Canada | <input type="radio"/> Sydney, Australia |
| <input type="radio"/> Tacoma, Washington | <input type="radio"/> Tebessa, Algeria | <input type="radio"/> Teheran, Iran | <input type="radio"/> Tel Aviv-Jaffa, Israel | <input type="radio"/> Thessaloniki, Greece | <input type="radio"/> Tijuana, Mexico |
| <input type="radio"/> Tokyo, Japan | <input type="radio"/> Ulan Bator, Mongolia | <input type="radio"/> Valledupar, Colombia | <input type="radio"/> Victoria, Canada | <input type="radio"/> Vienna, Austria | <input type="radio"/> Vijayawada, India |
| <input type="radio"/> Warszawa, Poland | <input type="radio"/> Yerevan, Armenia | <input type="radio"/> Yiyang, China | <input type="radio"/> Yulin, China | <input type="radio"/> Zhengshou, China | <input type="radio"/> Zugdidi, Georgia |

Canada, St. Catharines : Site 2



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

Scene Elements

(no more than five)

residential

- ☐ high density
- ☐ low density
- ☐ single houses
- ☐ slum, informal

built-up

- ☐ industrial, commercial, institutional
- ☐ roads, airports, ports
- ☐ mines, quarries, construction

agriculture

- ☐ large fields, pasture
- ☐ small fields, pasture
- ☐ vineyards, nurseries, plantations

undeveloped land

- ☐ forest, tundra
- ☐ savanna, shrubs, grasses
- ☐ barren, desert, rock

water

- ☐ permanent ice
- ☐ wetland, marsh
- ☐ water, river, lake, canal
- ☐ flooded land

unknown

- ☐ cloud cover
- ☐ low resolution
- ☐ other

Submit

Clear

Canada, St. Catharines : Site 6



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

Scene Elements

(no more than five)

- residential
 - ☐ high density
 - ☐ low density
 - ☐ single houses
 - ☐ slum, informal
- built-up
 - ☐ indust'l, commerc'l, institut'l
 - ☐ roads, airports, ports
 - ☐ mines, quarries, construction
- agriculture
 - ☐ large fields, pasture
 - ☐ small fields, pasture
 - ☐ vineyards, nurseries, plantations
- undeveloped land
 - ☐ forest, tundra
 - ☐ savanna, shrubs, grasses
 - ☐ barren, desert, rock
 - ☐ permanent ice
- water
 - ☐ wetland, marsh
 - ☐ water, river, lake, canal
 - ☐ flooded land
- unknown
 - ☐ cloud cover
 - ☐ low resolution
 - ☐ other

Submit

Clear

Canada, St. Catharines : Site 26



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

Scene Elements

(no more than five)

- residential
 - ☐ high density
 - ☐ low density
 - ☐ single houses
 - ☐ slum, informal
- built-up
 - ☐ indust'l, commerc'l, institut'l
 - ☐ roads, airports, ports
 - ☐ mines, quarries, construction
- agriculture
 - ☐ large fields, pasture
 - ☐ small fields, pasture
 - ☐ vineyards, nurseries, plantations
- undeveloped land
 - ☐ forest, tundra
 - ☐ savanna, shrubs, grasses
 - ☐ barren, desert, rock
 - ☐ permanent ice
- water
 - ☐ wetland, marsh
 - ☐ water, river, lake, canal
 - ☐ flooded land
- unknown
 - ☐ cloud cover
 - ☐ low resolution
 - ☐ other

Submit

Clear

Canada, St. Catharines : Site 1



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

Scene Elements

residential

built-up

agriculture

undeveloped land

water

unknown

(no more than five)

- ☐ high density
- ☐ low density
- ☐ single houses
- ☐ slum, informal
- ☐ indust'l, commerc'l, institut'l
- ☐ roads, airports, ports
- ☐ mines, quarries, construction
- ☐ large fields, pasture
- ☐ small fields, pasture
- ☐ vineyards, nurseries, plantation
- ☐ forest, tundra
- ☐ savanna, shrubs, grasses
- ☐ barren, desert, rock
- ☐ permanent ice
- ☐ wetland, marsh
- ☐ water, river, lake, canal
- ☐ flooded land
- ☐ cloud cover
- ☐ low resolution
- ☐ other

Submit

Clear

France, Paris : Site 28



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

Scene Elements

(no more than five)

residential

- ☐ high density
- ☐ low density
- ☐ single houses
- ☐ slum, informal

built-up

- ☐ indust'l, commerc'l, institut'l
- ☐ roads, airports, ports
- ☐ mines, quarries, construction

agriculture

- ☐ large fields, pasture
- ☐ small fields, pasture
- ☐ vineyards, nurseries, plantations

undeveloped land

- ☐ forest, tundra
- ☐ savanna, shrubs, grasses
- ☐ barren, desert, rock

water

- ☐ permanent ice
- ☐ wetland, marsh
- ☐ water, river, lake, canal
- ☐ flooded land

unknown

- ☐ cloud cover
- ☐ low resolution
- ☐ other

Submit

Clear

India, Mumbai : Site 1



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

Scene Elements

residential

(no more than five)

- ☐ high density
- ☐ low density
- ☐ single houses
- ☐ slum, informal
- ☐ built-up
- ☐ industrial, commercial, institutional
- ☐ roads, airports, ports
- ☐ mines, quarries, construction
- ☐ agriculture
- ☐ large fields, pasture
- ☐ small fields, pasture
- ☐ vineyards, nurseries, plantation
- ☐ undeveloped land
- ☐ forest, tundra
- ☐ savanna, shrubs, grasses
- ☐ barren, desert, rock
- ☐ permanent ice
- ☐ water
- ☐ wetland, marsh
- ☐ water, river, lake, canal
- ☐ flooded land
- ☐ unknown
- ☐ cloud cover
- ☐ low resolution
- ☐ other

Submit

Clear

Rwanda, Kigali : Site 22



Urban-Rural

- 1 ☐ all urban (built-up)
- 2 ☐ majority urban (built-up)
- 3 ☐ even mix
- 4 ☐ majority rural (non-built)
- 5 ☐ all rural (non-built)

Recent Change

- ☐ new construction
- ☐ fire
- ☐ flood

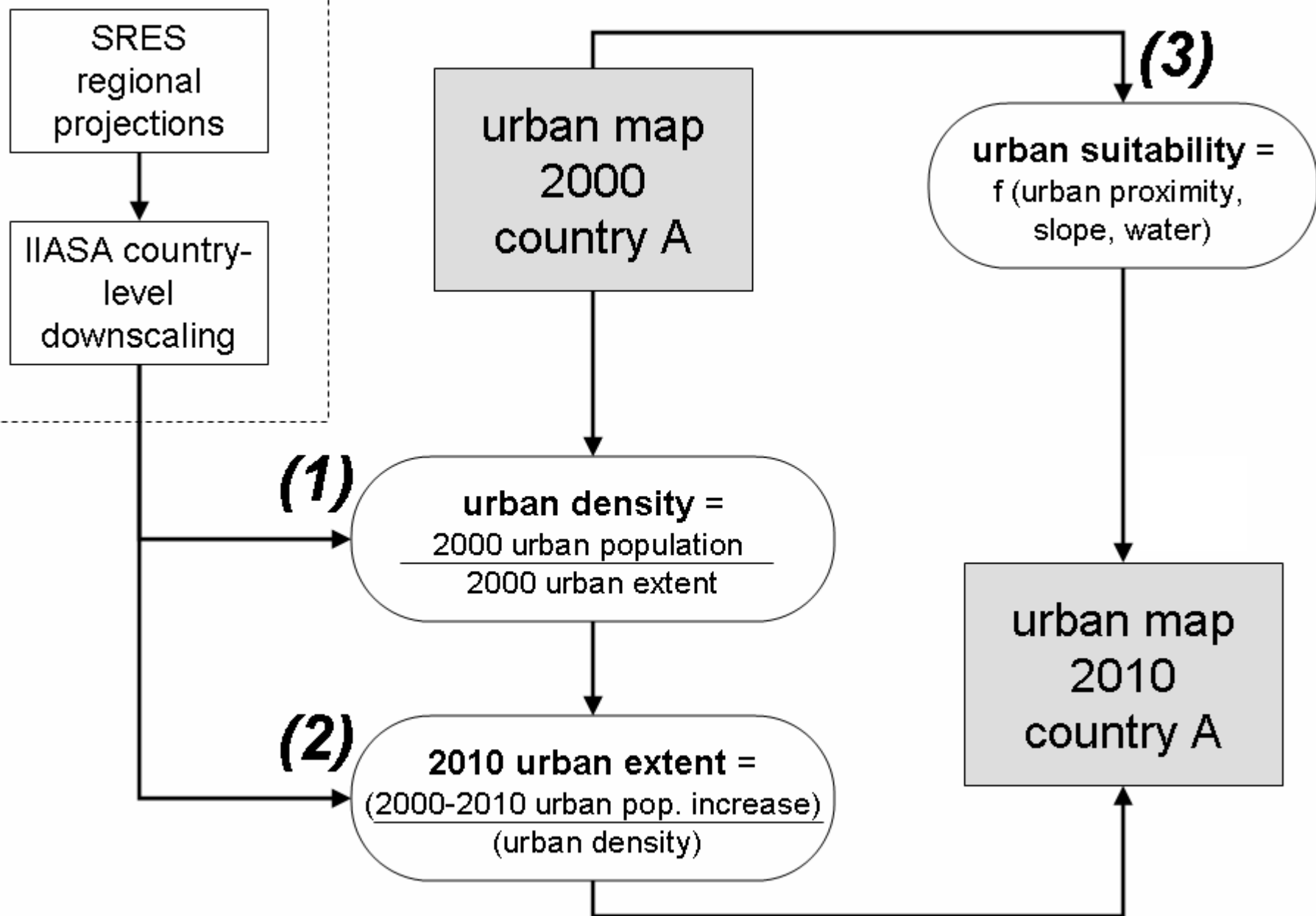
Scene Elements

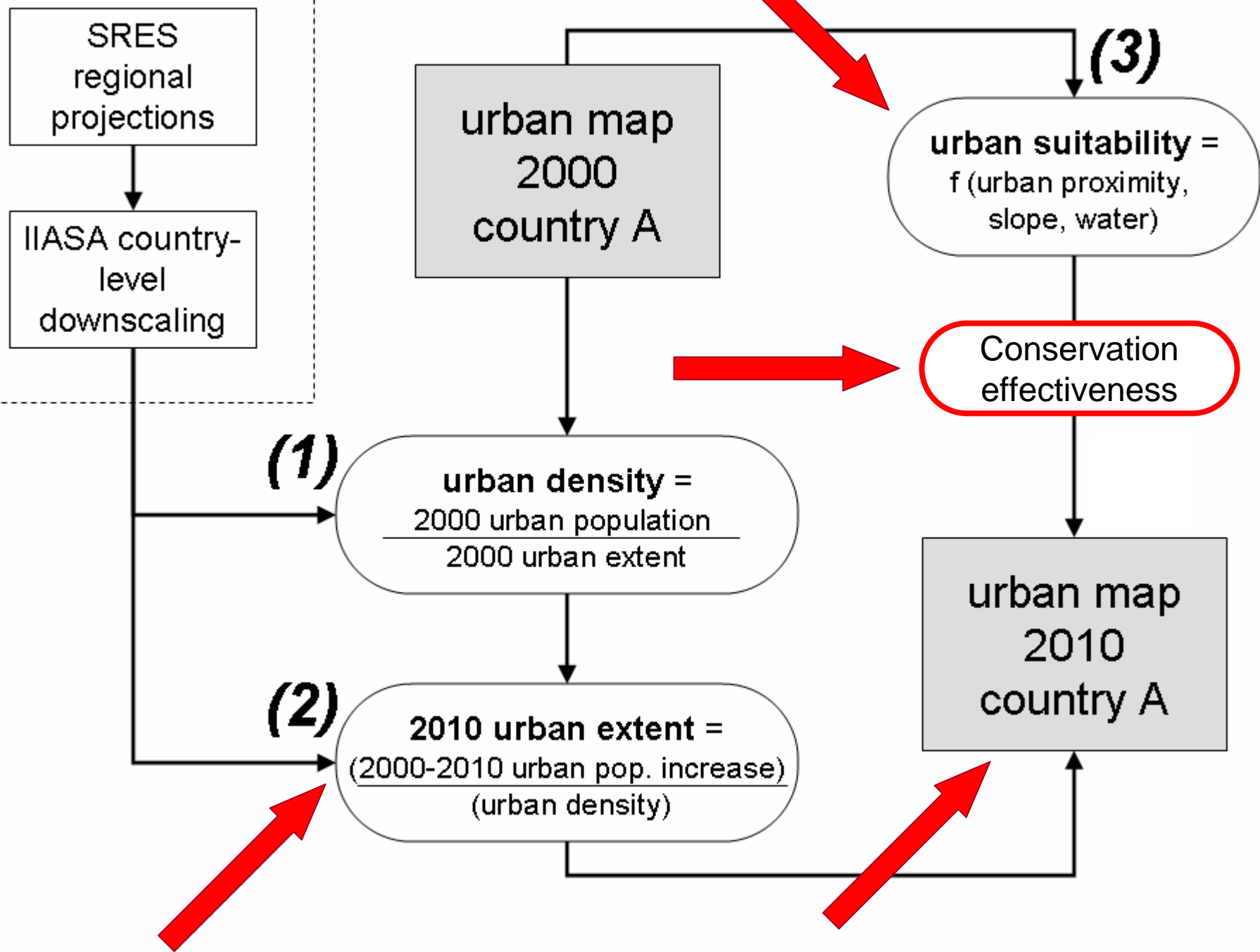
(no more than five)

- residential
 - ☐ high density
 - ☐ low density
 - ☐ single houses
 - ☐ slum, informal
- built-up
 - ☐ indust'l, commerc'l, institut'l
 - ☐ roads, airports, ports
 - ☐ mines, quarries, construction
- agriculture
 - ☐ large fields, pasture
 - ☐ small fields, pasture
 - ☐ vineyards, nurseries, plantations
- undeveloped land
 - ☐ forest, tundra
 - ☐ savanna, shrubs, grasses
 - ☐ barren, desert, rock
 - ☐ permanent ice
- water
 - ☐ wetland, marsh
 - ☐ water, river, lake, canal
 - ☐ flooded land
- unknown
 - ☐ cloud cover
 - ☐ low resolution
 - ☐ other

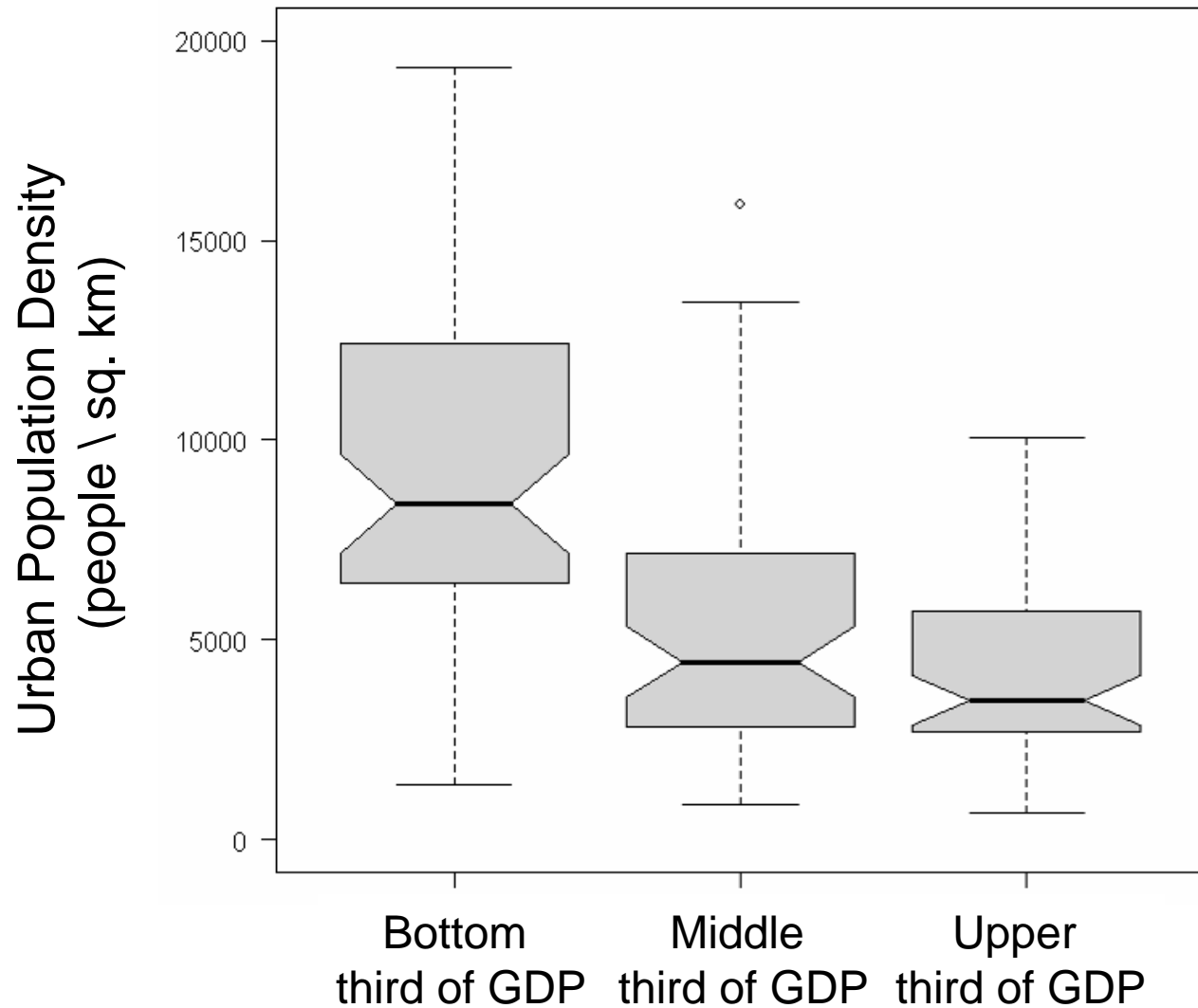
Submit

Clear



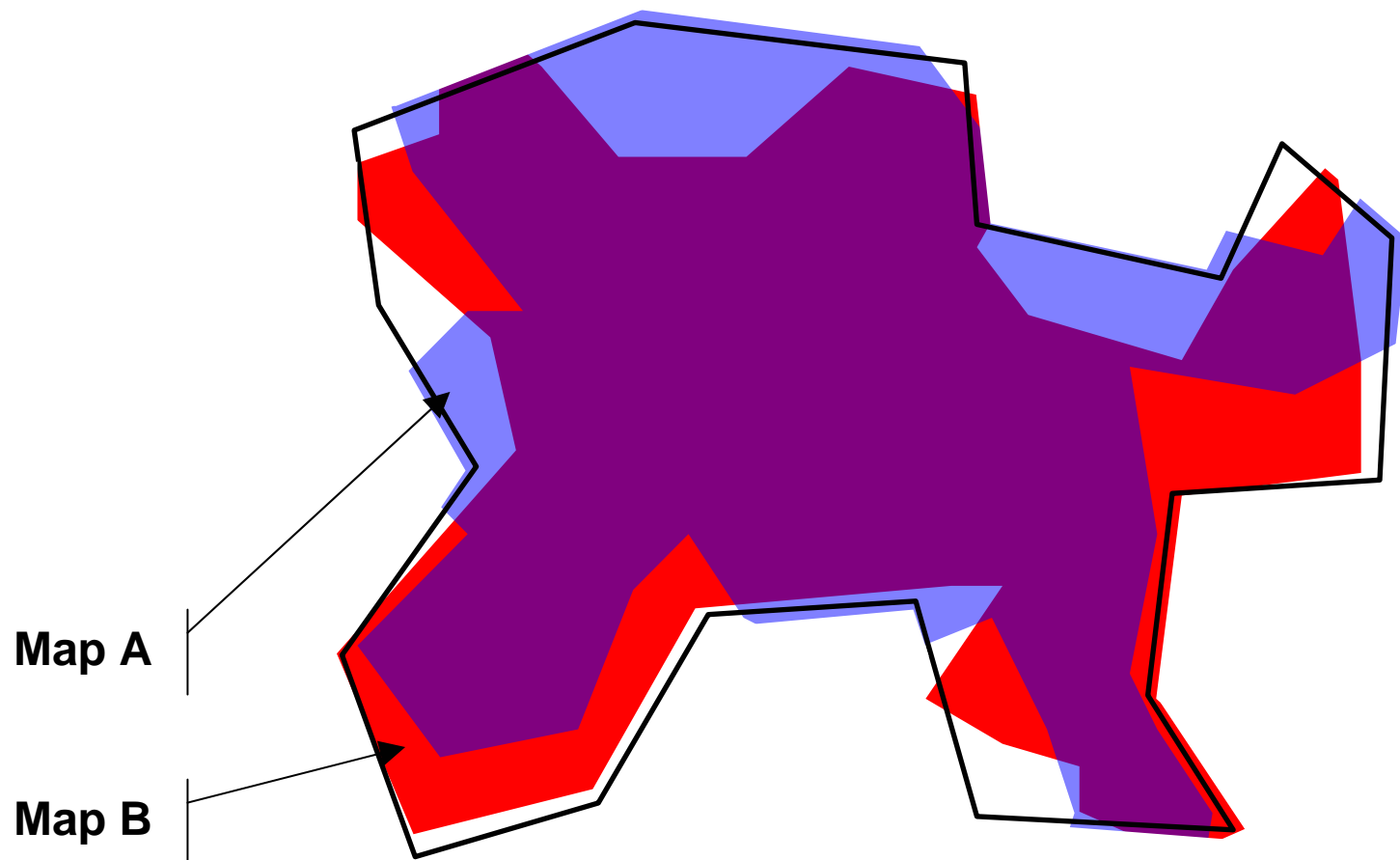


GDP versus urban density (n=120)



Assessment Results

	Omissions	Shape	Size
VMAP0	3	2	3
GLC00	3	2	2
HYDE	2	2	2
IMPSA	1	1	2
MOD500	1	1	1
MOD1K	2	2	2
GRUMP	2	2	3



Contingency Matrix

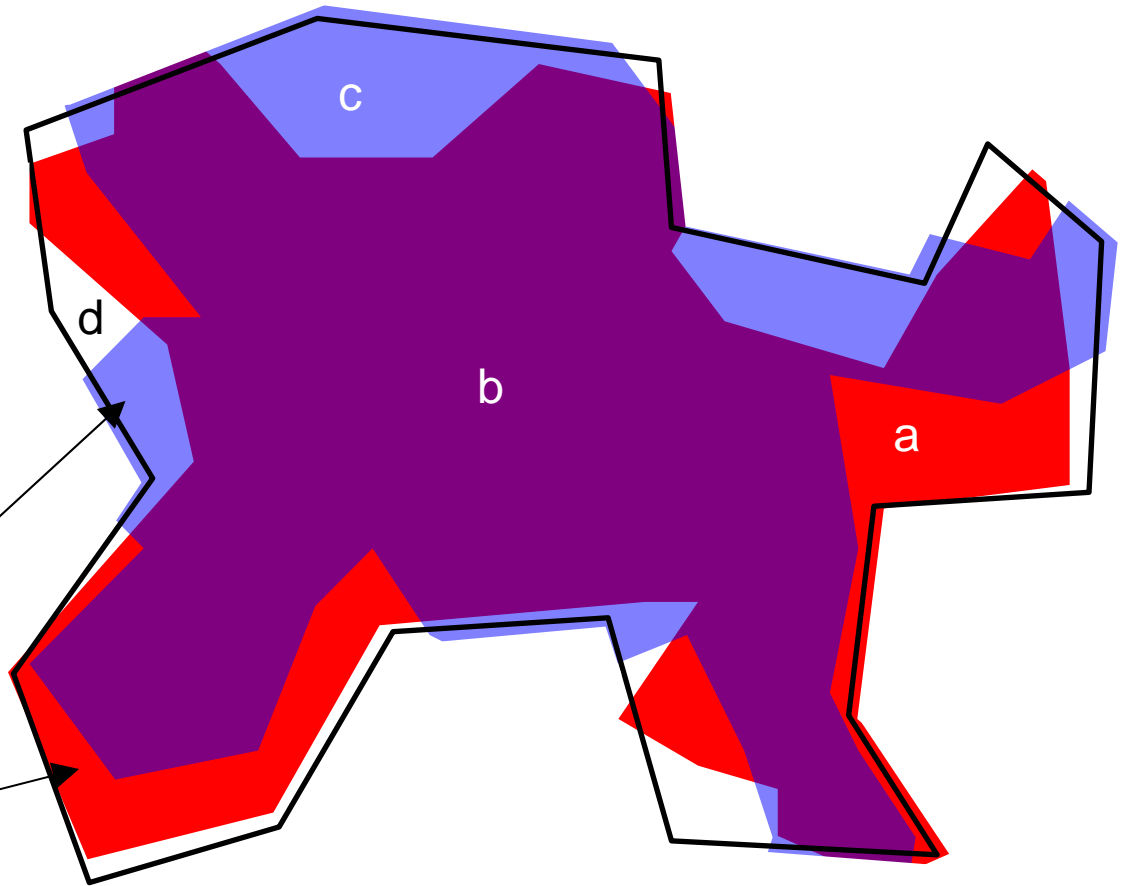
	Map B Urban	Map B Rural
Map A Urban	a	b
Map A Rural	c	d

Commission Error

Omission Error

Map A

Map B



Map Agreement Statistics

Contingency Table

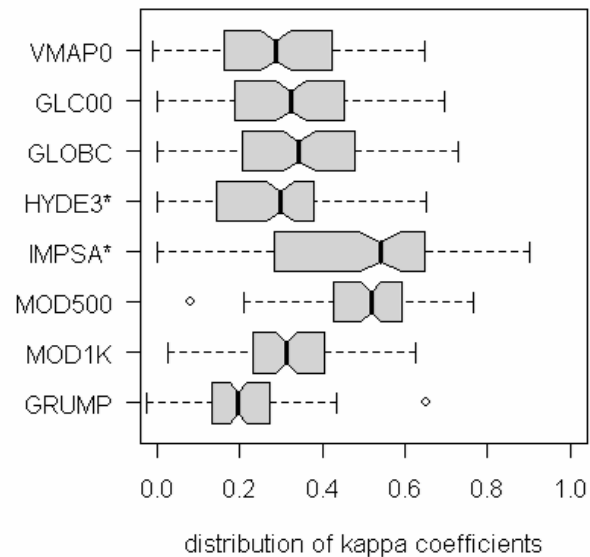
$n = a + b + c + d$		Validation Data	
		Presence	Absence
Review Data	Presence	a	b
	Absence	c	d

Overall map accuracy (OMA)	$\frac{a + d}{n}$
Specificity (1-Commission)	$\frac{d}{b + d}$
Sensitivity (1-Omission)	$\frac{a}{a + c}$

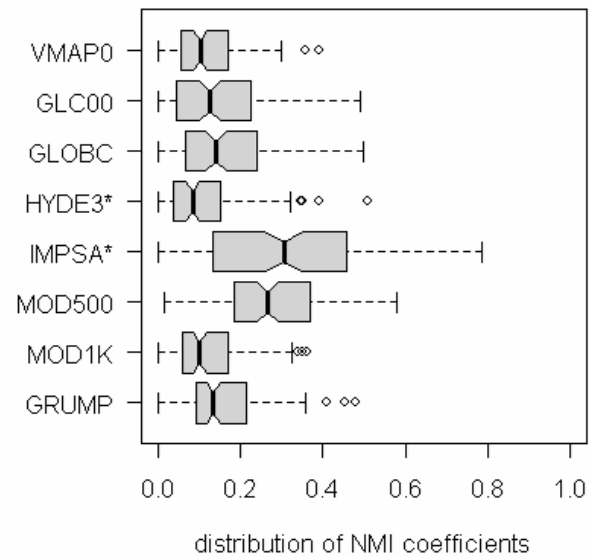
Cohen's Kappa	$\frac{\left(\frac{a+d}{n}\right) - \frac{(a+b)(a+c) + (c+d)(d+b)}{n^2}}{1 - \frac{(a+b)(a+c) + (c+d)(d+b)}{n^2}}$
Normalized Mutual Information	$1 - \frac{-a \ln(a) - b \ln(b) - c \ln(c) - d \ln(d) + (a+b) \ln(a+b) + (c+d) \ln(c+d)}{n \ln(n) - ((a+c) \ln(a+c) + (b+d) \ln(b+d))}$
True Skill Statistic	$\frac{ad - bc}{(a+c)(b+d)} \quad \text{or, sensitivity + specificity} - 1$

Map agreement distributions (n=120)

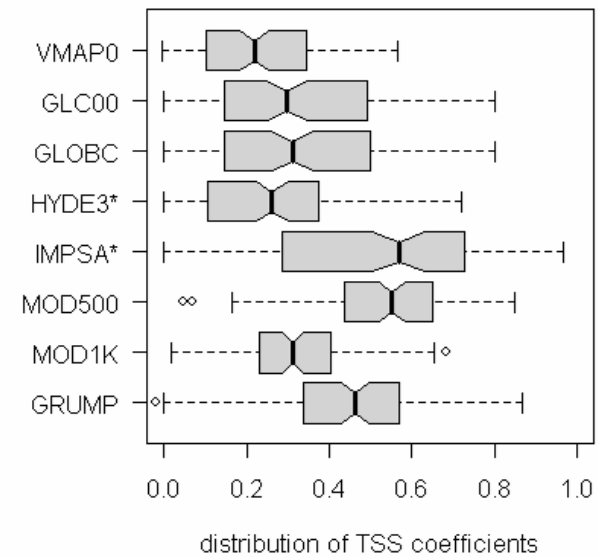
Cohen's Kappa Statistic



Normalized Mutual Information

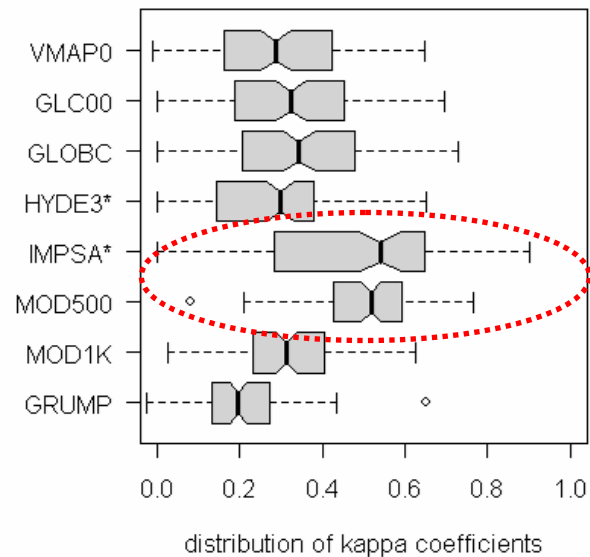


True Skill Statistic

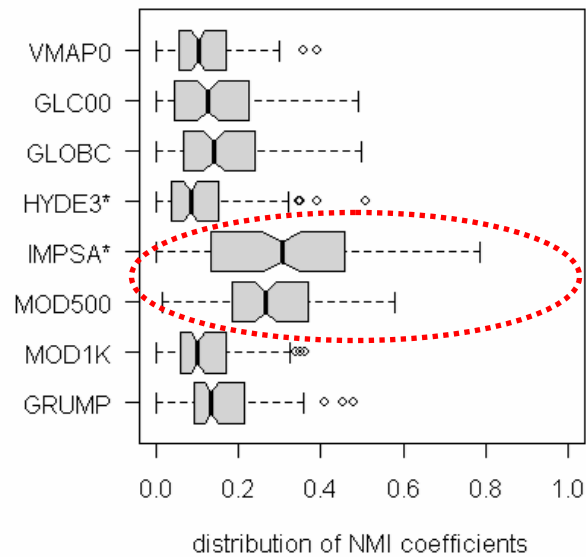


Map agreement distributions (n=120)

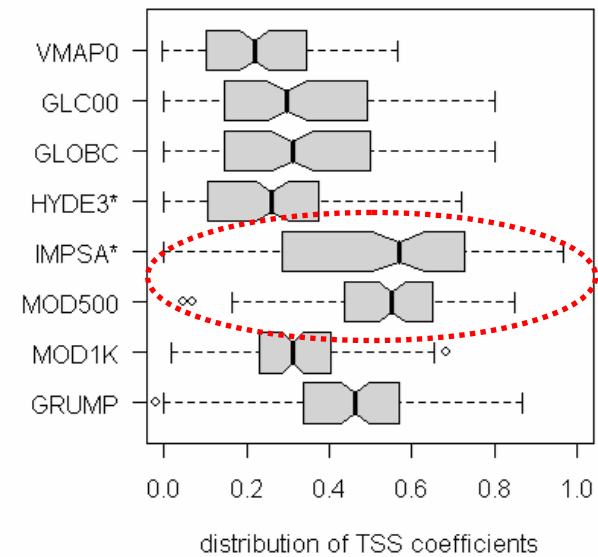
Cohen's Kappa Statistic

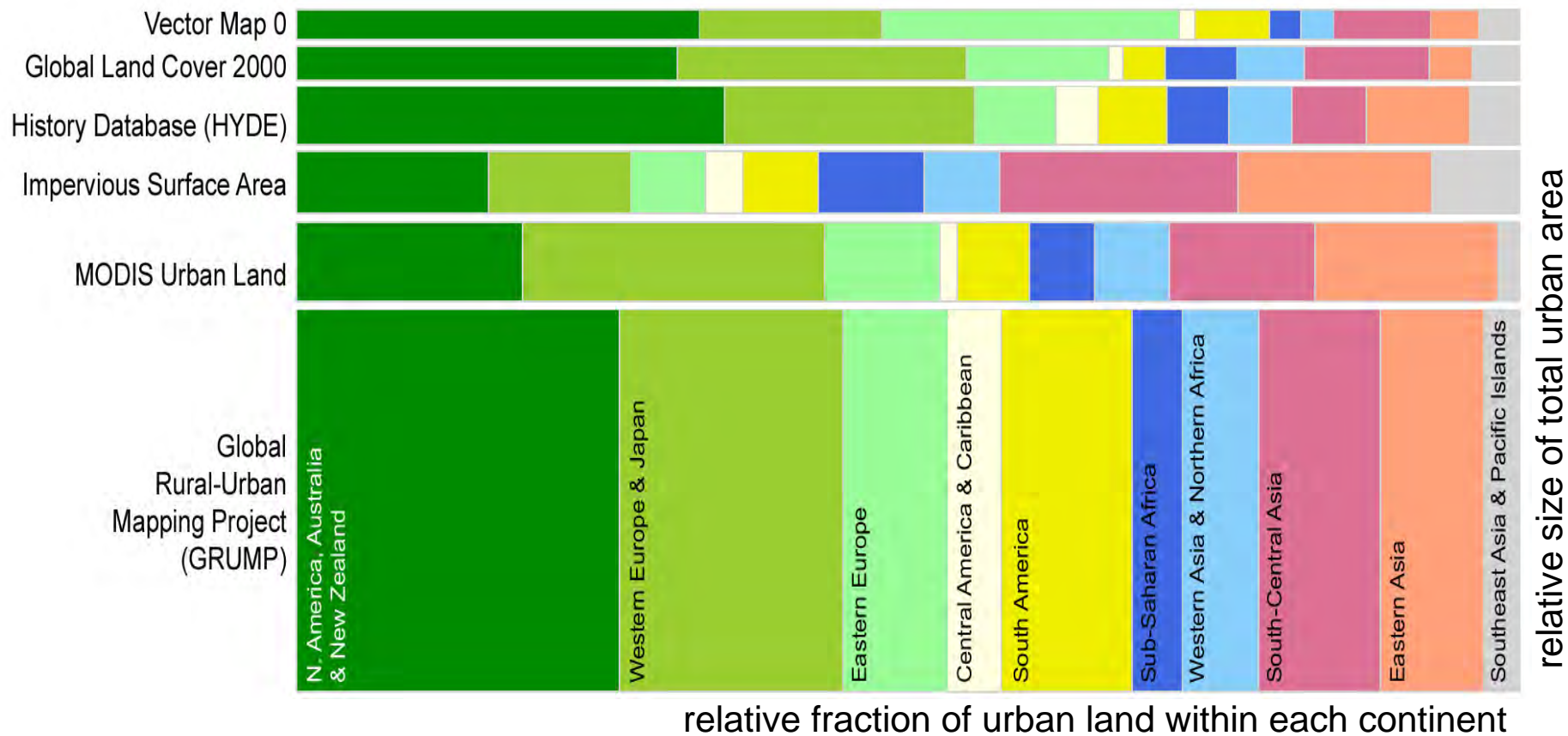


Normalized Mutual Information

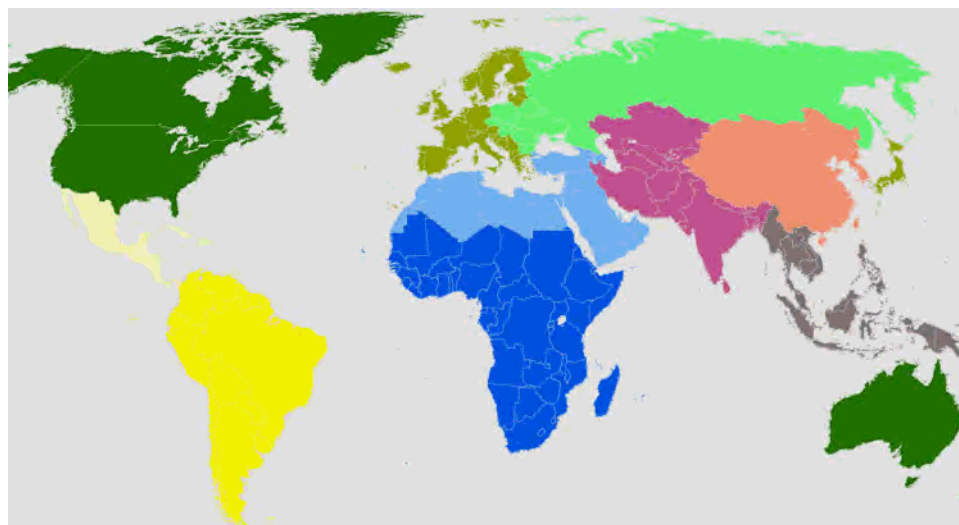


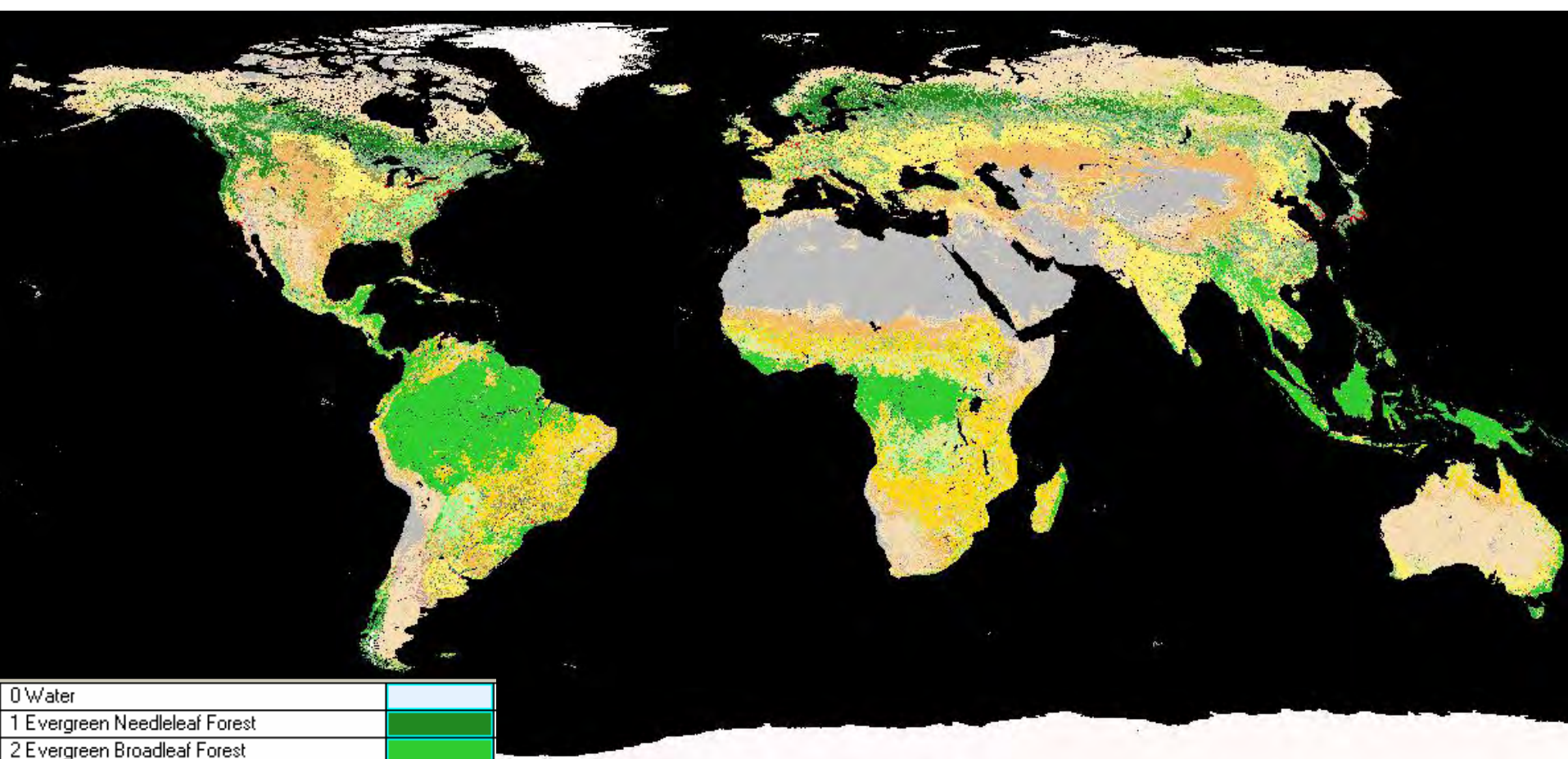
True Skill Statistic

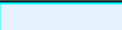



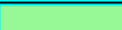












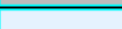


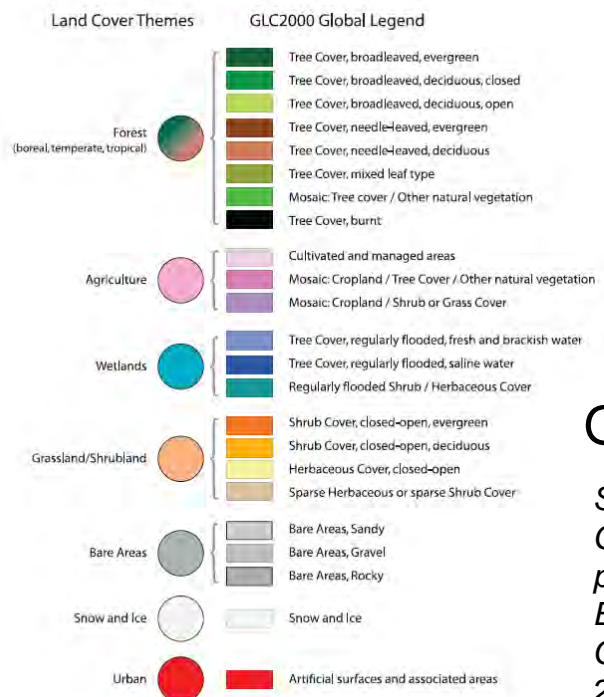
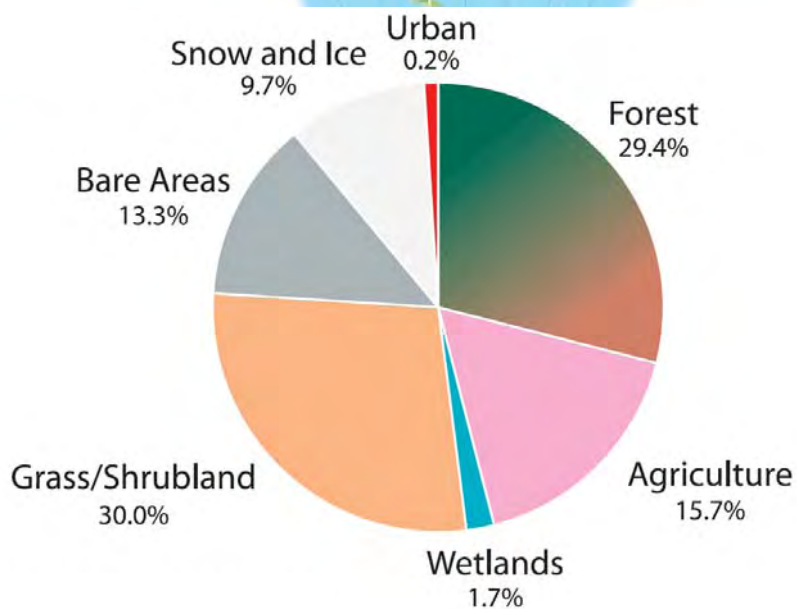
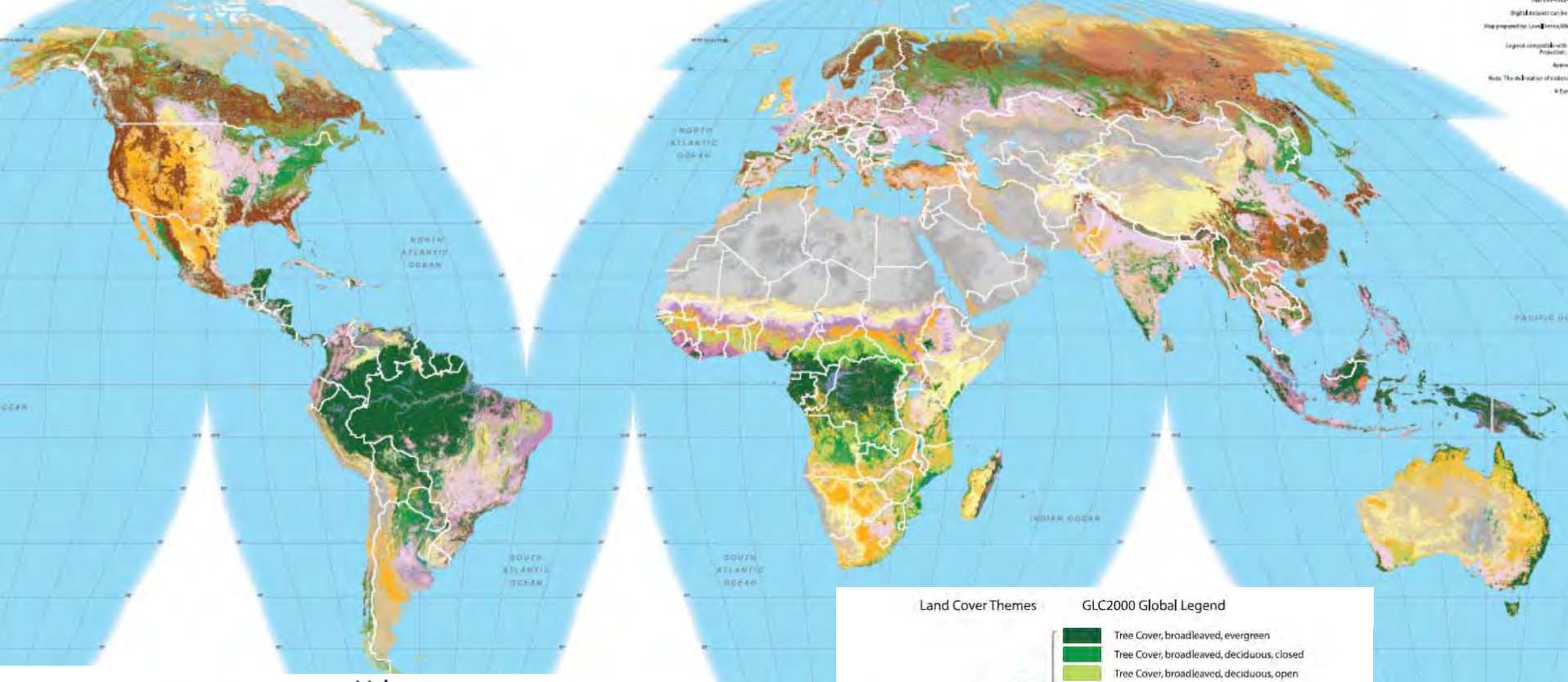


Cartogram
of total urban area,
by world-region





0 Water	
1 Evergreen Needleleaf Forest	
2 Evergreen Broadleaf Forest	
3 Deciduous Needleleaf Forest	
4 Deciduous Broadleaf Forest	
5 Mixed Forests	
6 Closed Shrublands	
7 Open Shrublands	
8 Woody Savannas	
9 Savannas	
10 Grasslands	
11 Permanent Wetlands	
12 Croplands	
13 Urban and Built-Up	
14 Cropland/Natural Vegetation Mosaic	
15 Snow and Ice	
16 Barren or Sparsely Vegetated	
17 (Water Bodies, recoded to 0)	



GLC 2000

*Source:
GLC2000
poster,
European
Commission,
2004.*

Methods

	Primarily image-based				Combination			Map-based	
	MOD500	MOD1K	GLOBC	GLC00	IMPSA	LSCAN	HYDE3	GRUMP	VMAP0
Imagery									
High Res.					Various ^a				
Medium Res.	Landsat	Landsat		Landsat	Landsat ^b	GeoCover ^c			
Coarse Res.	MODIS 500m, '01	MODIS 1km, '01	MERIS 300m, '05	SPOT4- VGT 2001					
Night Lights		1996-97		1994-95	2000-01 ^d			1994-95	
Census & Maps									
Census						US ^e	UN ^f	UN ^f	
Maps / Charts	X	X	X			X		X	X
City Gazetteers						X		X	X
Road Vectors			X			X			
Global Maps									
VMAP	level 0					level 1 ^g	level 0	level 0	
MODIS						2001			
GLC-2000	2001						2001		
LandScan					2004		2005		

MOD500

GLOBC

GLC00

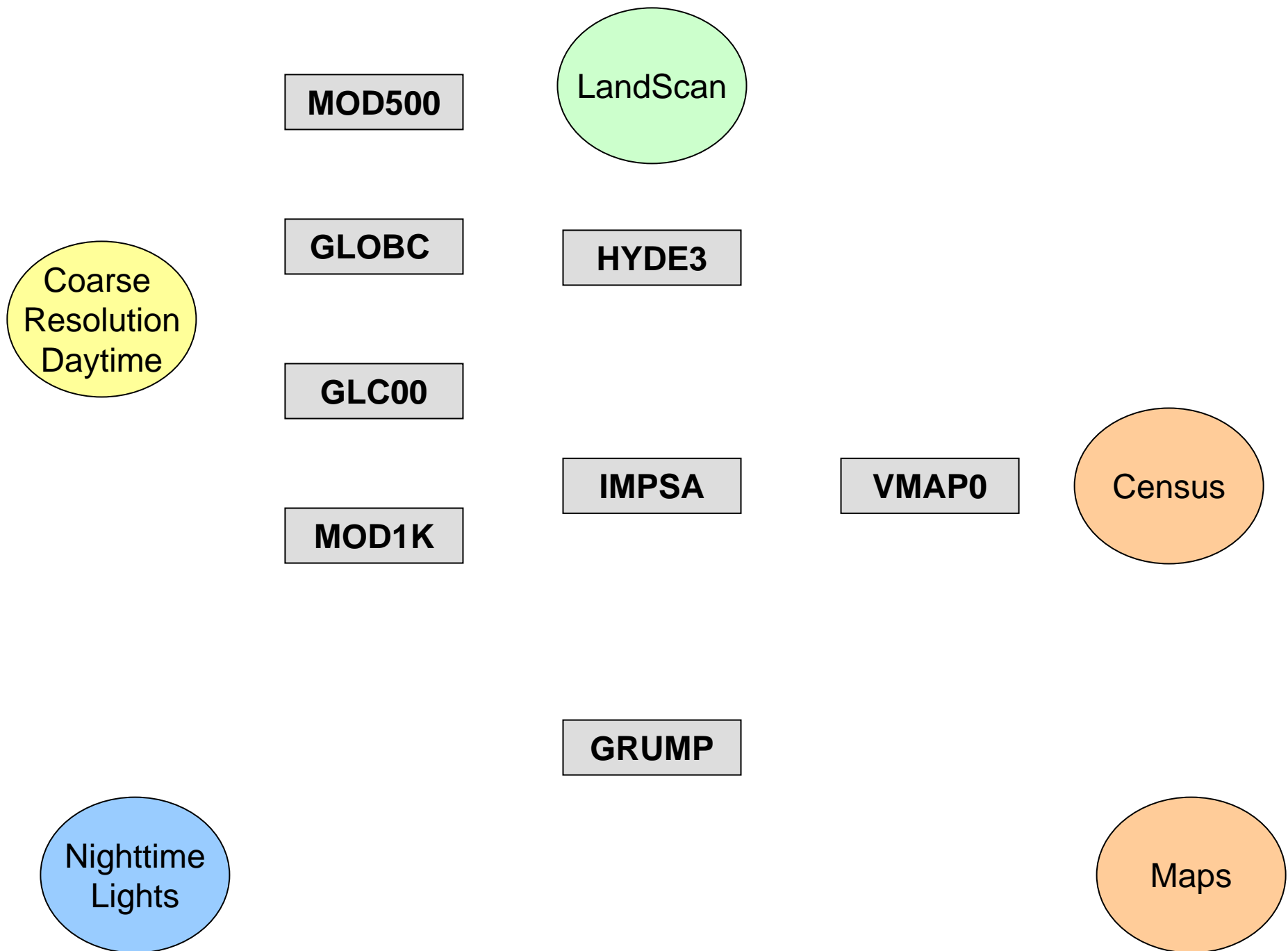
MOD1K

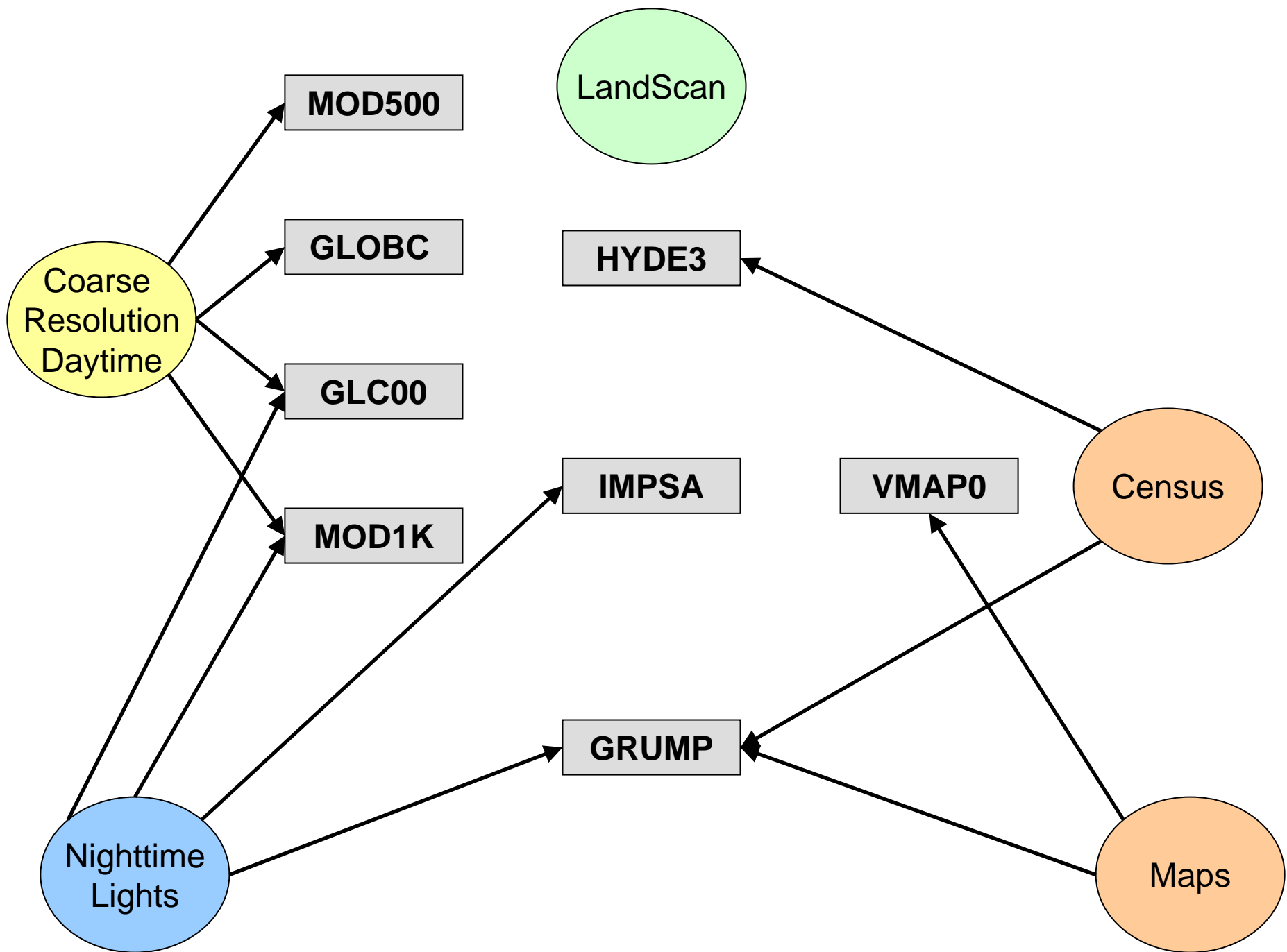
HYDE3

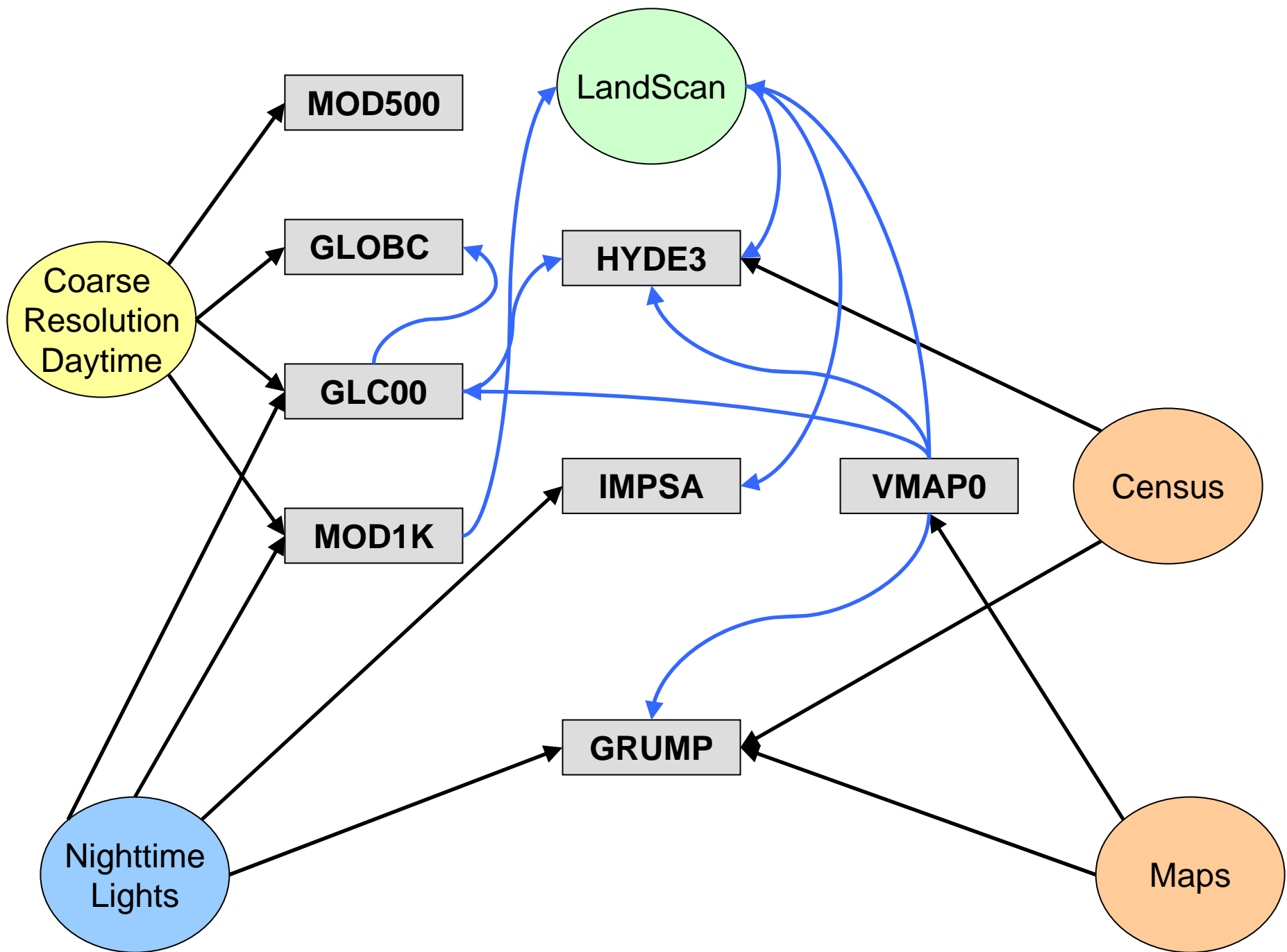
IMPSA

GRUMP

VMAP0



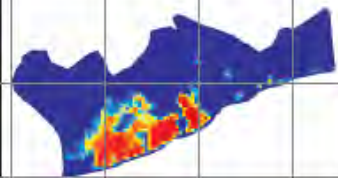




Methods for six Global Urban Maps

	Population	Primarily Image-Based		Combination		Map-Based	
	LSCAN	MODIS	GLC00	IMPISA	GRUMP	HYDE3	VMAP0
Imagery							
High Resolution	various ¹						
Medium Res.	GeoCover ²	Landsat	Landsat	Landsat			
Coarse Res.		MODIS	SPOT-VGT				
Nighttime Lights		1994-95	1994-95	2000-01	1994-95		
Census & Maps							
Annual Census	US ⁴				UN ⁷	UN ⁷	
Maps / Charts	X	X	X		X		X
City Gazetteers	X				X		X
Road Vectors	X						
Global Maps							
VMAP	lev. 0 & 1 ⁶		lev. 0 ⁵		lev. 0	lev. 0	
MODIS	2001						
GLC-2000						2001	
LandScan				2004		2005	

U.Conn. Landsat



Accra, Ghana

2/4/2000

City Size Estimates

	area	% urban	% Uconn
UConn	302	15%	100%
VMAPO	25	1%	10%
GLC00	430	21%	142%
HYDE3	115	5%	35%
IMP8A	209	10%	69%
MODIS	585	28%	195%
GRUMP	784	39%	260%
GEOCOVER	NA	NA	NA

(sq. km)

Contingency Metrics

Kappa	TSS	NMI
NA	NA	NA
0.15	0.09	0.06
0.71	0.83	0.53
0.38	0.29	0.15
0.85	0.95	0.76
0.32	0.38	0.11
0.43	0.72	0.37
NA	NA	NA

Centroid Offsets

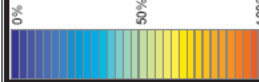
Bearing	Range
NA	NA
42	8.8
318	1.1
16	7.8
10	6.5
331	7.3
296	3.9
NA	NA

(deg) (km)

U.Conn. Landsat

The World Bank and the U. of Connecticut (UConn) produced maps of 120 cities using circa-2000 Landsat imagery and unsupervised classification techniques. Here, the 28.5 meter-resolution maps of urban and non-urban areas are aggregated to 30" arc-second pixels (approx. one sq. km at the equator) and shaded according to the percent of urban land within each pixel.

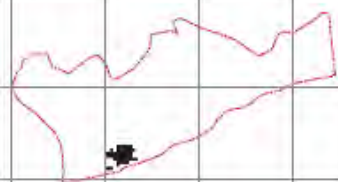
Percent Urban Land



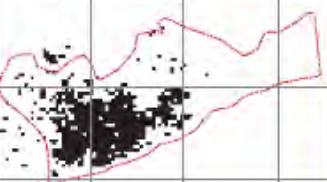
Map Descriptions & Legends

The maps are in a geographic projection, at 30" arc-second resolution (approx. 1 sq. km at the equator), oriented north-up, and co-registered to each other. The graticules within the maps (grid lines) are spaced at 0.25 degrees (15' arc-minutes). Although the true distance of their horizontal spacing varies by latitude, their vertical spacing is always roughly 27.8 km.

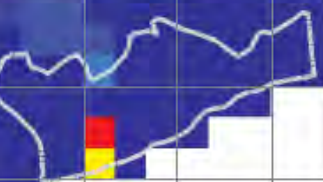
Vector Map 0



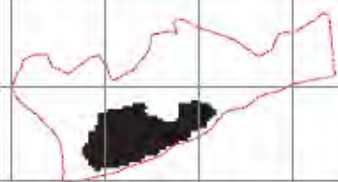
MODIS LC



HYDE v3



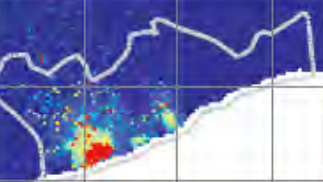
Global LC 2000



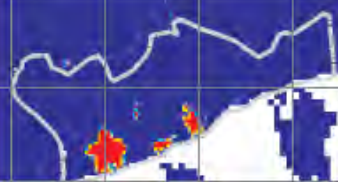
GRUMP



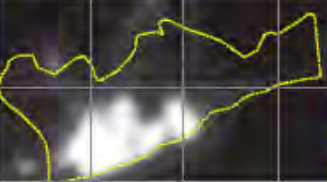
Global Imp. Surf. Area



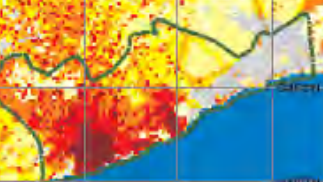
GeoCover LC



Night Lights



LandScan 2005



Vector Map 0

Vector Map Level Zero (VMAPO) was created by the US government by digitizing large collections of maps and navigational charts from the 1950s through the late 1950s at 1:1,000,000 scale. VMAPO was also the basis for the Digitized Chart of the World. Here, urban polygons are rasterized, and displayed at 30" arc-second resolution.

Non-Urban

Urban

MODIS LC

MODIS Land Cover Urban (MODIS LC) was created by Boston U. and NASA using a full year of observations from the MODIS satellite instrument (2001), nighttime lights imagery (1996-97), and various maps and charts. The BU team used medium resolution Landsat maps of various cities to calibrate their model.

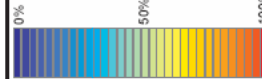
Non-Urban

Urban

HYDE v3

The History Database of the Global Environment (HYDE3) was created by the Netherlands Environmental Assessment Agency at 2.5 arc-minute resolution using a combination of census data (UN), VMAPO, GLC-2000, and Landsat.

Percent Urban Land



Global LC 2000

Global Landcover 2000 (GLC00) was created by the European Space Agency using a full year of data from the SPOT-VEG satellite (2000), nighttime lights imagery (1994-95), and VMAPO.

Non-Urban

Urban

GRUMP

The Global Rural-Urban Mapping Project (GRUMP) was completed by Columbia U. using a combination of nighttime lights imagery (1994-95), census data, maps and charts, city gazetteers, and vector map level zero.

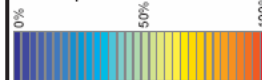
Non-Urban

Urban

Global Imp. Surf. Area

Global Impervious Surface Area (IMP8A) was created by the US National Geophysical Data Center (NGDC-NOAA) using one year of calibrated nighttime lights data (2000-01) and Landsat 2005. The NGDC used US impervious surface maps from the National Land Cover Database to calibrate their regression.

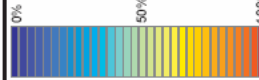
Percent Impervious Surface



GeoCover LC

GeoCover Land Cover (GEOCOVER) was produced from circa-1990 and circa-2000 Landsat imagery by a large group of analysts using unsupervised classification techniques. Because of gaps in the Landsat archive and cloud cover, GeoCover LC is not a global dataset. Only 72 of the 120 cities have circa-2000 GeoCover LC coverage.

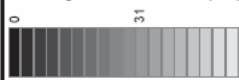
Percent Urban Land



Night Lights

Nighttime Lights (LITES) is produced by the National Geophysical Data Center using a full year of data from the Defense Meteorological Satellite Program Operational Line Scanner. Digital number (DN) values from 0-63 indicate how frequently the cloud-free observations showed evidence of stable human-produced lights. These maps display uncalibrated nighttime lights data from 2001 (P15 sensor).

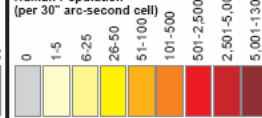
Annual Nighttime Illumination DN (0-63)



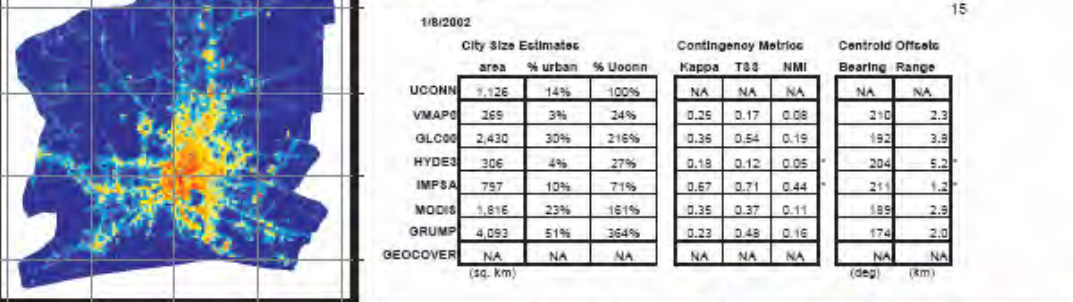
LandScan 2005

LandScan is produced by the Geographic Information Science Team at Oak Ridge National Lab (DOE) using a combination of high and medium res. imagery, GeoCover LC, census data (US), maps and charts, city gazetteers, road vectors, VMAPO, and MODIS LC.

Human Population

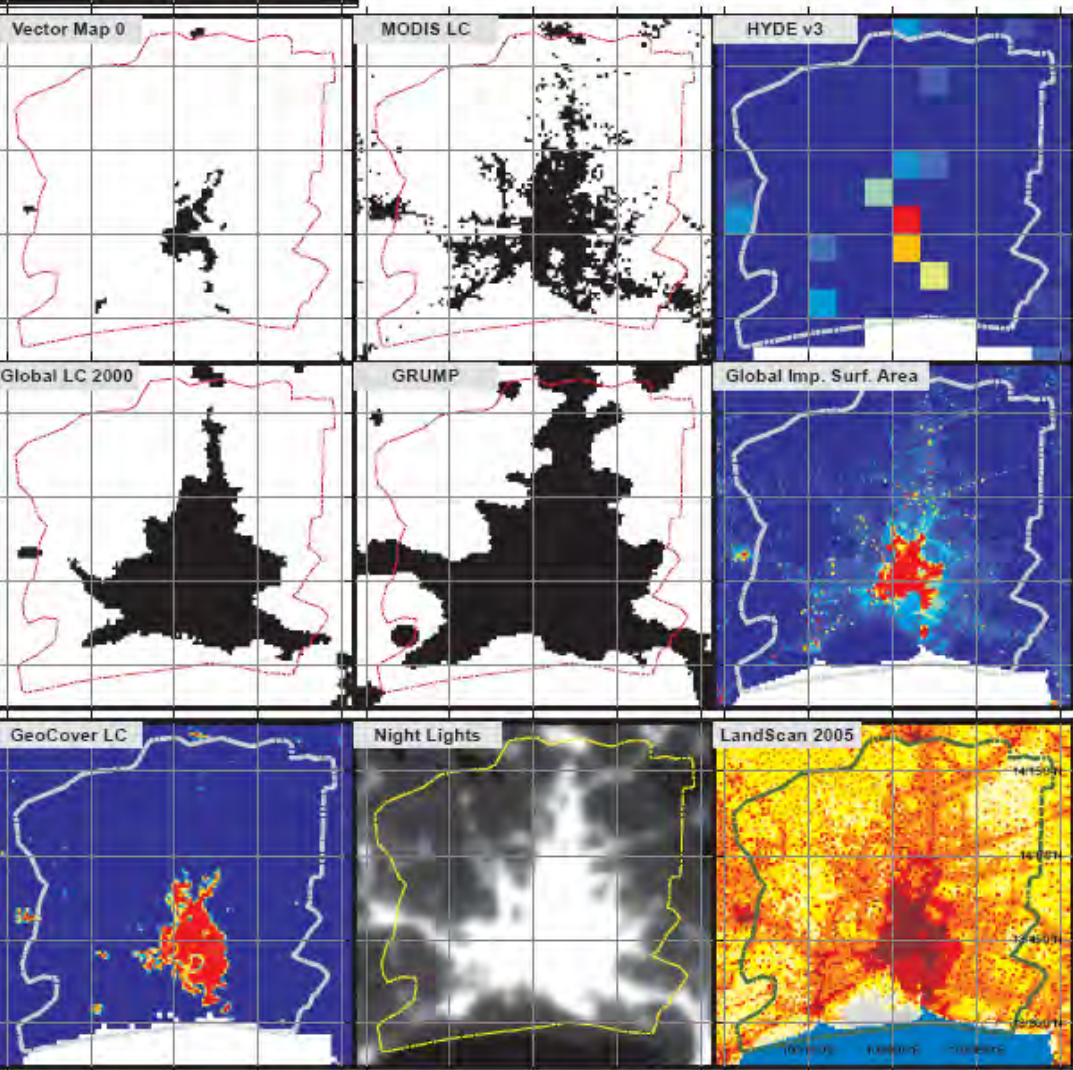
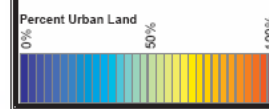


Accra, Ghana



The World Bank and the U. of Connecticut (UConn) produced maps of 120 cities using circa-2000 Landsat imagery and unsupervised classification techniques. Here, the 28.5 meter-resolution maps of urban and non-urban areas are aggregated to 30" arc-second pixels (approx. one sq. km at the equator) and shaded according to the percent of urban land within each pixel.

Percent Urban Land



Vector Map 0

Vector Map Level Zero (VMAPO) was created by the US government by digitizing large collections of maps and navigational charts from the 1950s through the late 1990s at 1:1,000,000 scale. VMAPO was also the basis for the Digitized Chart of the World. Here, urban polygons are rasterized, and displayed at 30" arc-second resolution.

Non-Urban Urban

MODIS LC

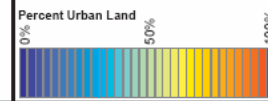
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Non-Urban Urban

HYDE v3

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Percent Urban Land



Global LC 2000

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Non-Urban Urban

GRUMP

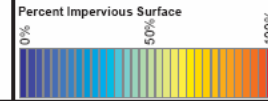
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Non-Urban Urban

Global Imp. Surf. Area

Global Impervious Surface Area (IMPBA) was created by the US National Geophysical Data Center (NGDC-NOAA) using one year of calibrated nighttime lights data (2000-01) and LandScan 2005. The NGDC used US impervious surface maps from the National Land Cover Database to calibrate their regression.

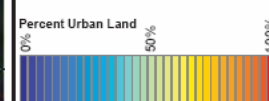
Percent Impervious Surface



GeoCover LC

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Percent Urban Land



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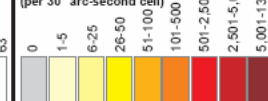
Annual Nighttime Illumination DN (0-63)



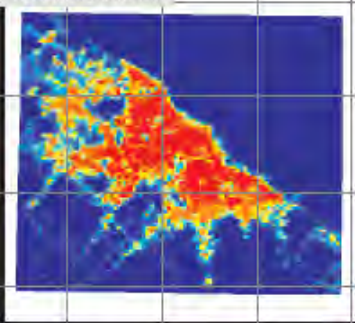
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Human Population (per 30" arc-second cell)



Bangkok, Thailand



12/20/2000

City Size Estimates

	area	% urban	% Uconn
UCONN	1,377	31%	100%
VMAPO	975	22%	71%
GLC00	703	16%	51%
HYDE3	1,580	36%	115%
IMP&A	1,166	25%	85%
MODIS	2,163	49%	157%
GRUMP	3,784	85%	275%
GEOCOVER	1,614	37%	117%

(sq. km)

Contingency Metrics

	Kappa	TSS	NMI
UCONN	NA	NA	NA
VMAPO	0.51	0.47	0.21
GLC00	0.50	0.43	0.23
HYDE3	0.60	0.62	0.30
IMP&A	0.78	0.78	0.53
MODIS	0.43	0.45	0.16
GRUMP	0.13	0.20	0.07
GEOCOVER	0.77	0.81	0.53

Centroid Offsets

	Bearing	Range
UCONN	NA	NA
VMAPO	341	6.0
GLC00	181	3.8
HYDE3	77	0.5
IMP&A	274	1.5
MODIS	42	1.4
GRUMP	70	3.0
GEOCOVER	358	7.0

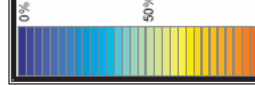
(deg)

(km)

U.Conn. Landsat

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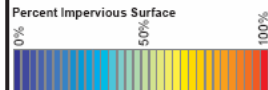
GRUMP

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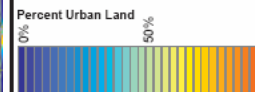
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GeoCover LC

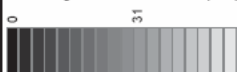
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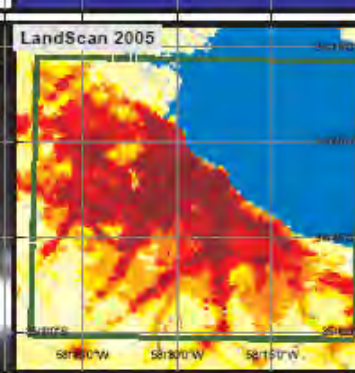
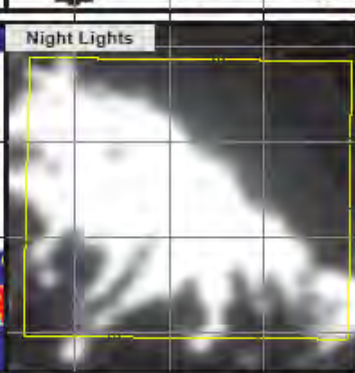
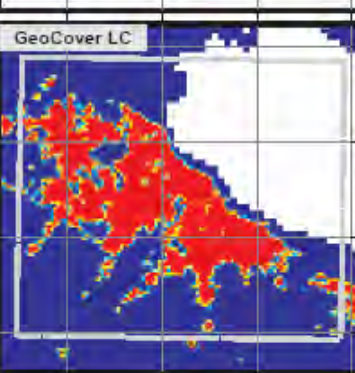
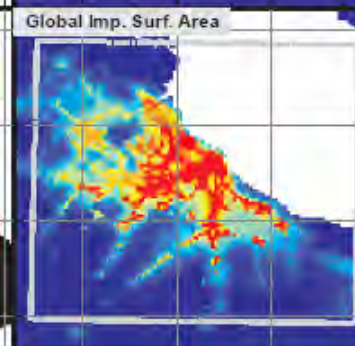
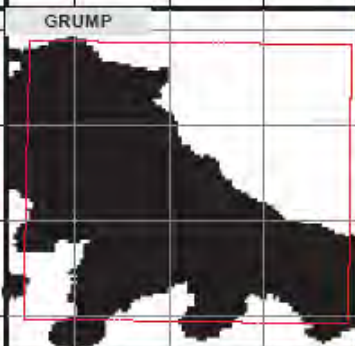
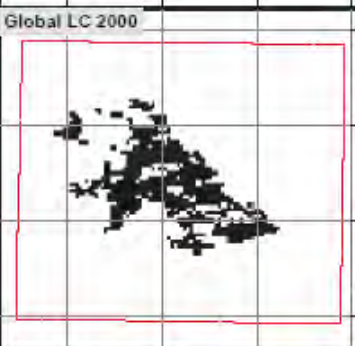
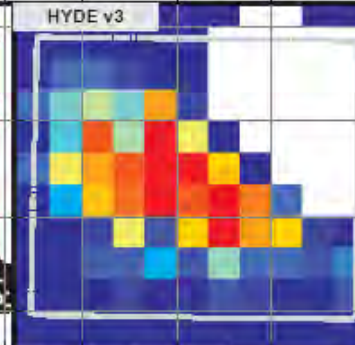
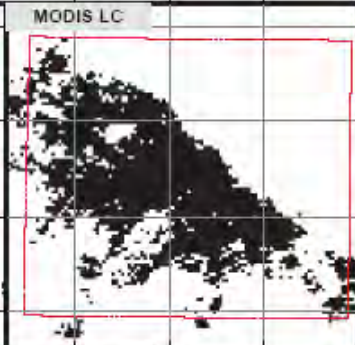
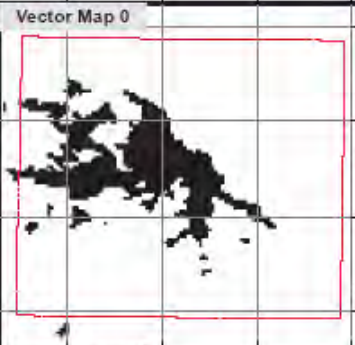
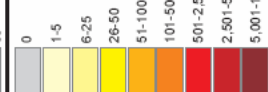
Annual Nighttime Illumination DN (0-63)



LandScan 2005

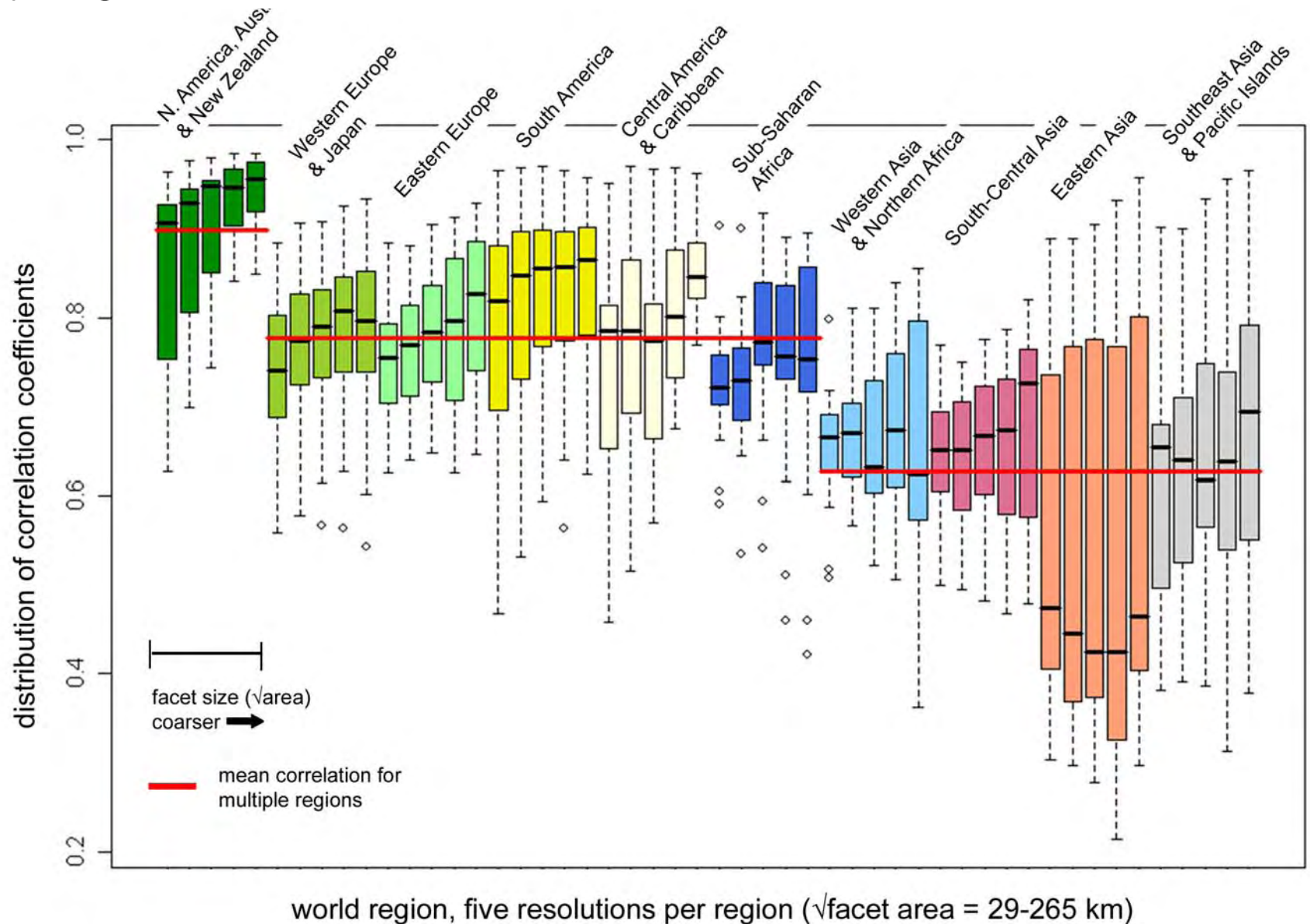
LandScan is produced by the Geographic Information Science Team at Oak Ridge National Lab (DOE) using a combination of high and medium res. imagery, GeoCover LC, census data (US), maps and charts, city gazetteers, road vectors, VMAPO, and MODIS LC.

Human Population (per 30" arc-second cell)

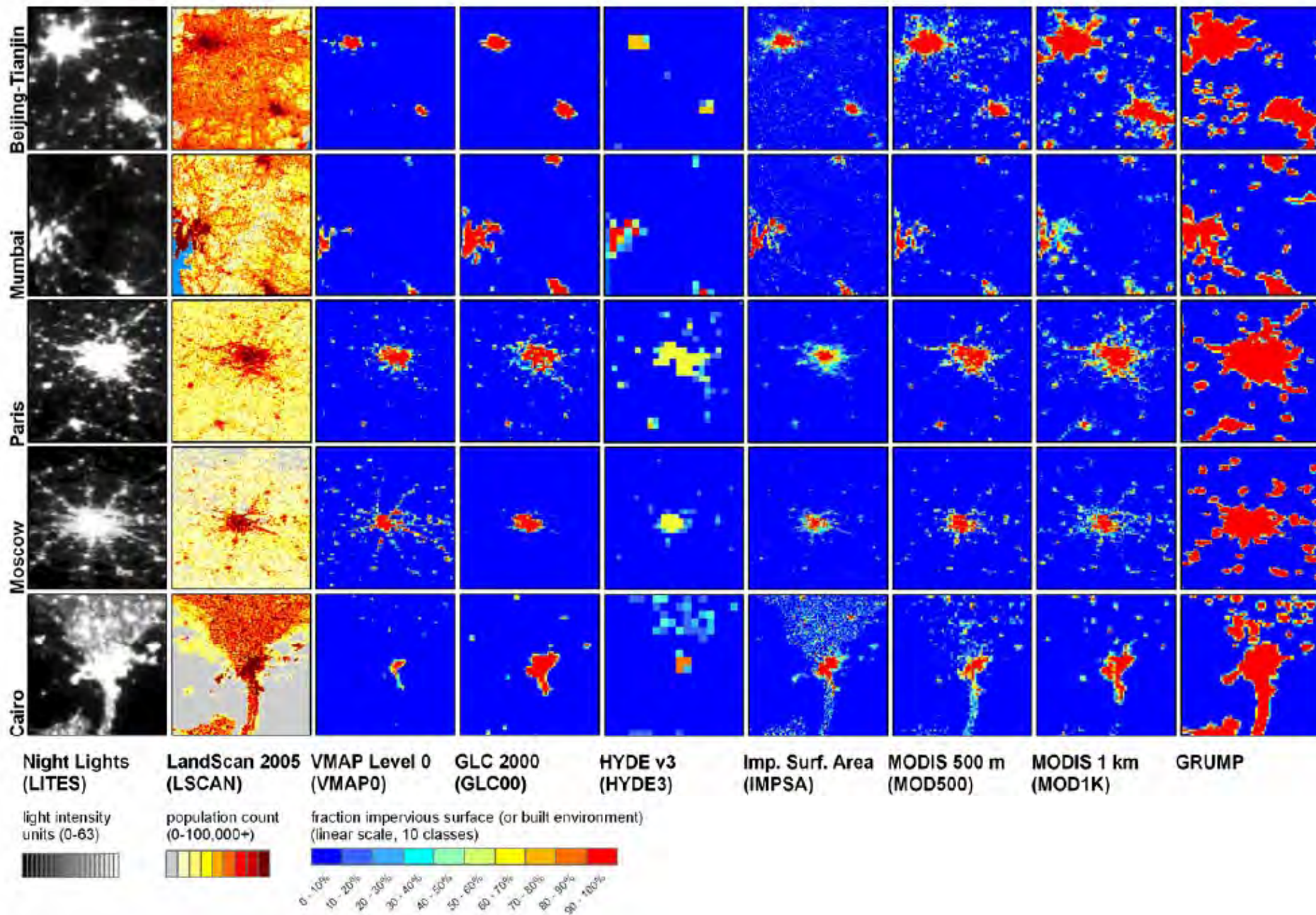


Buenos Aires, Argentina

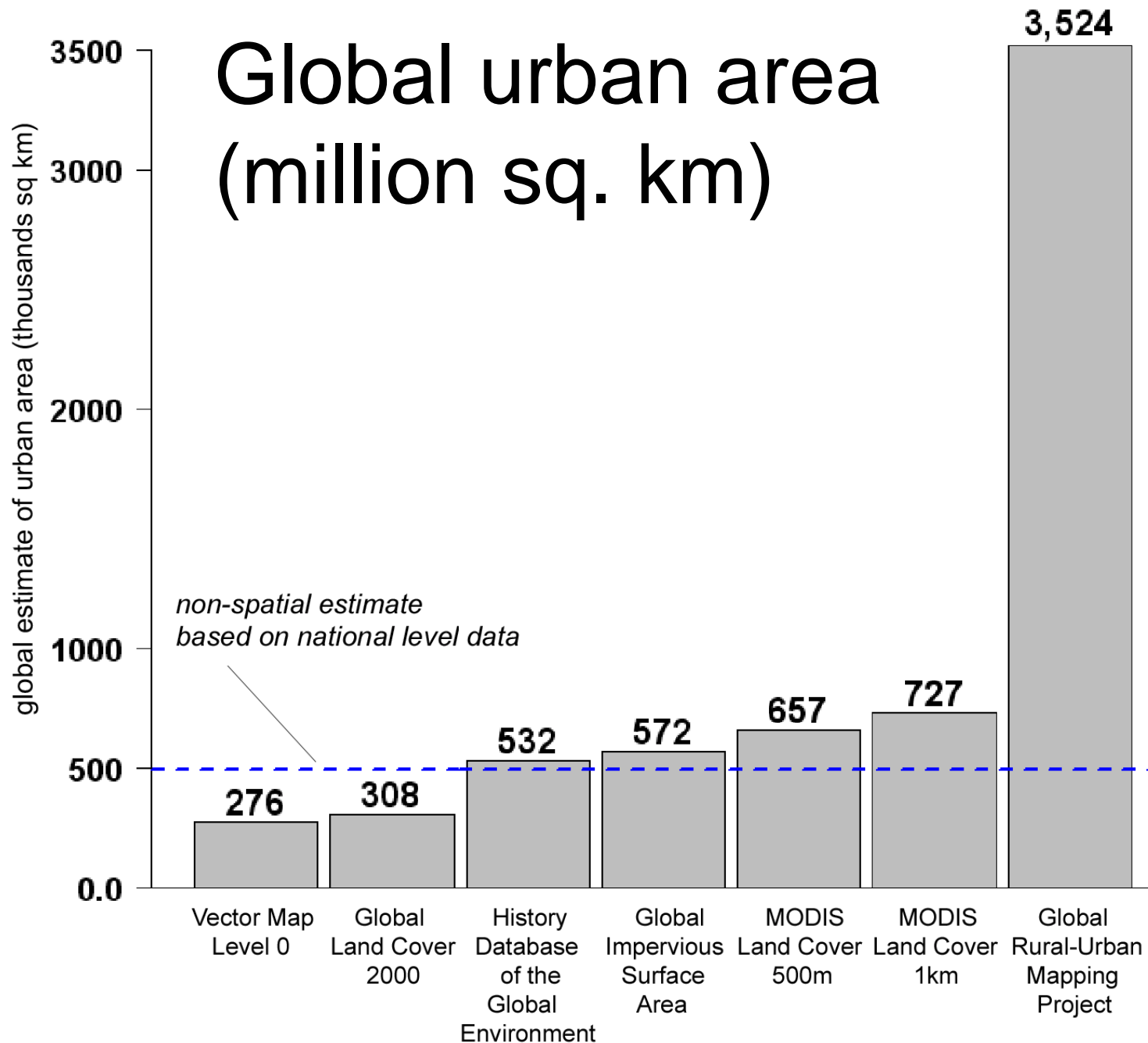
Inter-map correlations across all 15 map pairs by region, five resolutions



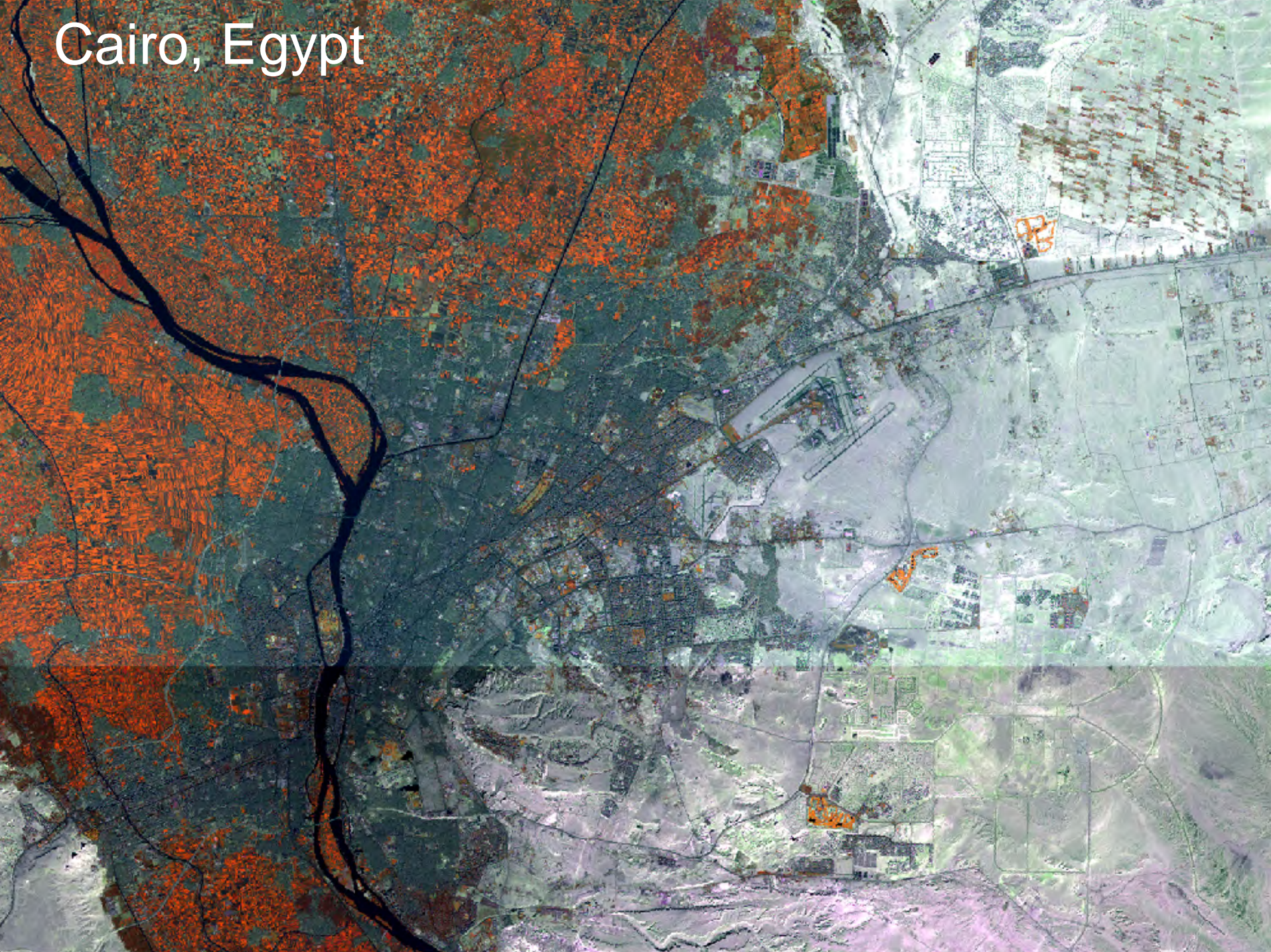
City-scale comparisons



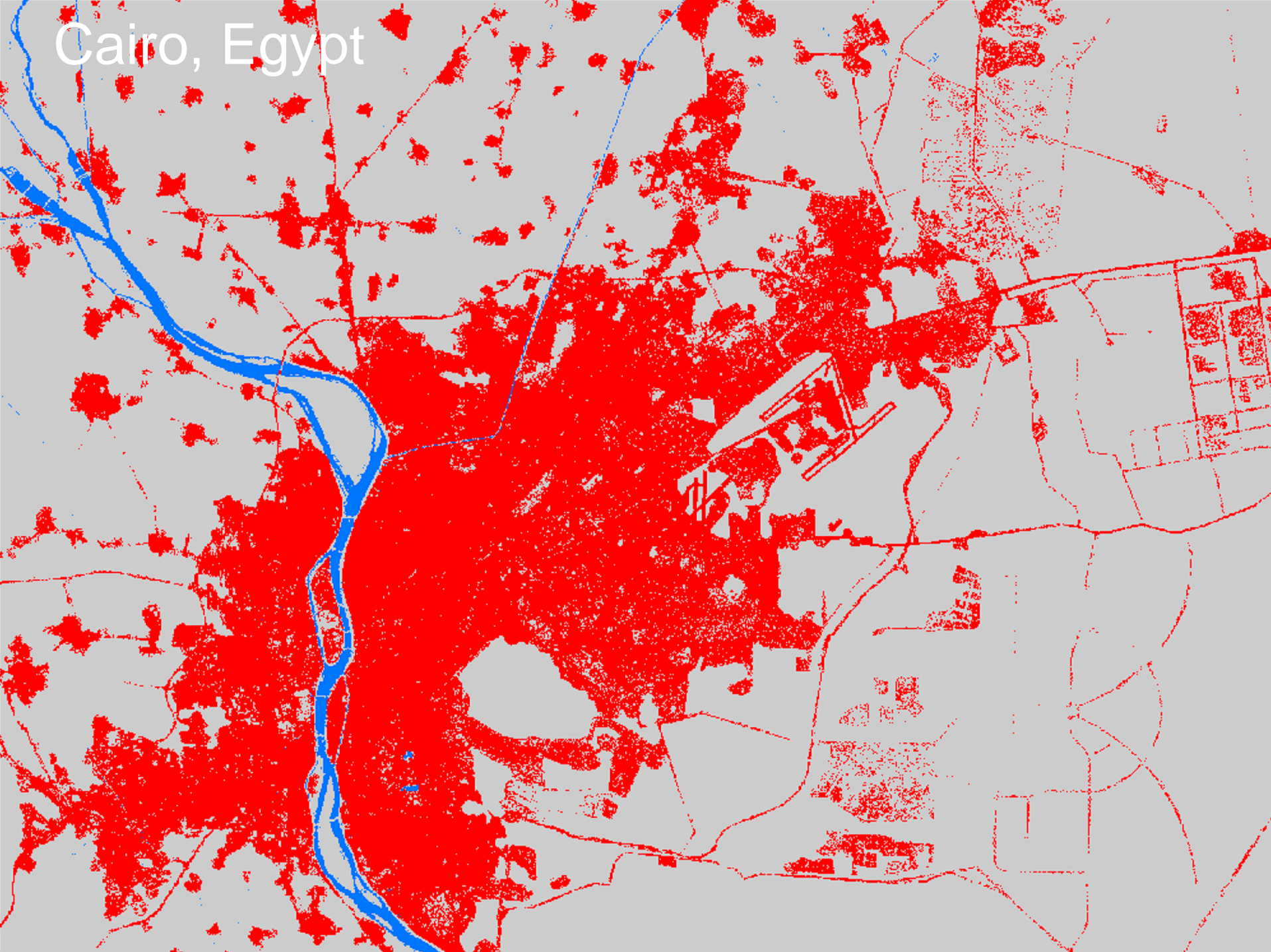
Global urban area (million sq. km)



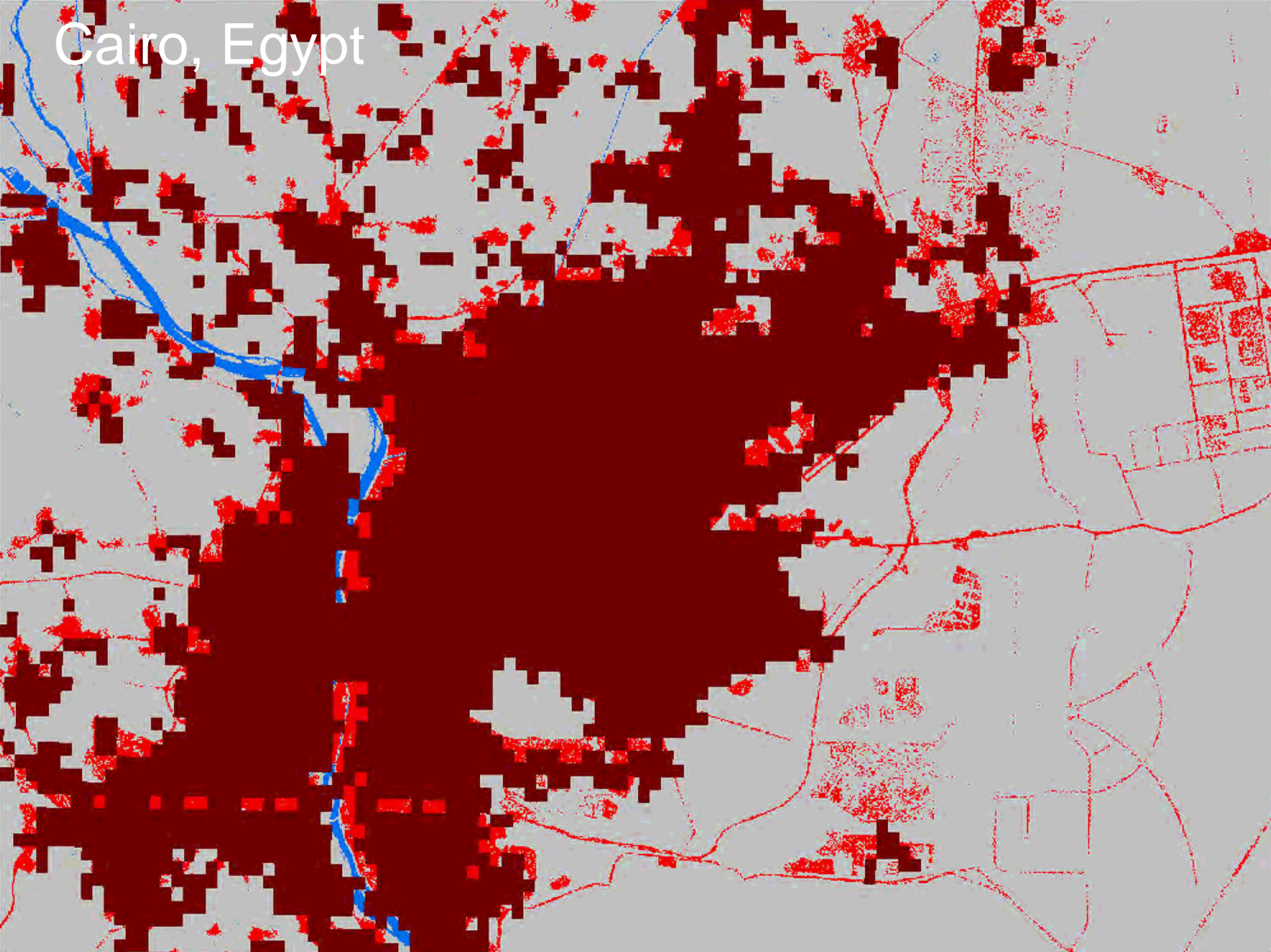
Cairo, Egypt



Cairo, Egypt



Cairo, Egypt



City Name (Population 2000, x1000)		VMAPO	GLC00	HYDE3	IMPSA	MOD500	MOD1K	GRUMP	Regional Omission Rates
Zhengshou, China	(2,070)		0						East Asia (56%) (9/16)
Yulin, China	(1,558)	<5	0						
Leshan, China	(1,373)	<5							
Yiyang, China	(1,343)		0					<5	
Ulan Bator, Mongolia	(738)			<5					
Changzhi, China	(594)		0						
Anging, China	(566)		0						
Chinju, Korea	(287)		0						
Chonan, Korea	(114)		<5						
Baku, Azerbaijan	(1,936)		<5						W. Asia (63%) (5/8)
Sanaa, Yemen	(1,653)		<5						
Yerevan, Armenia	(1,407)		0						
Malata, Turkey	(437)		0						
Zugdidi, Georgia	(105)		<5						
Gorgan, Iran	(189)		0						SC Asia (6%) (1/16) SE Asia (8%) (1/12)
Cebu, Philippines	(719)						<5		
Vallendupar, Columbia	(274)		0						
Ilheus, Brazil	(162)	0							Latin Am. (19%) (3/16)
Jequie, Brazil	(130)	0	<5						
Banjul, Gambia	(399)	<5							
Kigali, Rwanda	(351)	<5	0						SS Africa (17%) (2/12)
Port Sudan, Sudan	(384)	<5	0					<5	
Tebessa, Algeria	(163)	<5							
Fukuoka, Japan	(1,341)		<5						N. Africa (25%) (2/8)
Total Omissions		8	18	1	0	0	1	2	ODC + Europe (3%) (1/32)
Omission Rate (120 cities)		7%	15%	1%	0%	0%	1%	2%	
		VMAPO	GLC00	HYDE3	IMPSA	MOD500	MOD1K	GRUMP	

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- Prevent large, permanent biodiversity losses
- Provide ecosystem services
- Improve human health and well-being

How do urban
and protected
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- Direct urban incursions on protected areas
- Alterations in local-to-regional ecosystems (climate, biodiversity, pollution, etc.)

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- Two billion new urbanites through 2030
- Most expansion in developing countries
- Declining urban densities

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