CENTER FOR EARTH SYSTEM SCIENCE
清华全球变化研究院

Global urbanization and surface heat differentials

Nick Clinton

China Daily, March 27, 2013:

“’Continued urbanization in China will drive the need for greater infrastructure investment, pointing to tremendous opportunities for Caterpillar,’ said Doug Oberhelman, chairman and chief executive officer of the U.S.-based construction equipment maker.”

“…the primary focus for Caterpillar's China strategy is on developing local leaders...”

- People’s Daily:

  “China considers more financial tools to aid urbanization: central banker”

- NTDT:

  “China’s Urbanization Drive Puts Trillions into Officials’ Pockets”

"Urbanization is the biggest potential force driving China's domestic demand in the years ahead"

-Zhang Ping

Car habitat

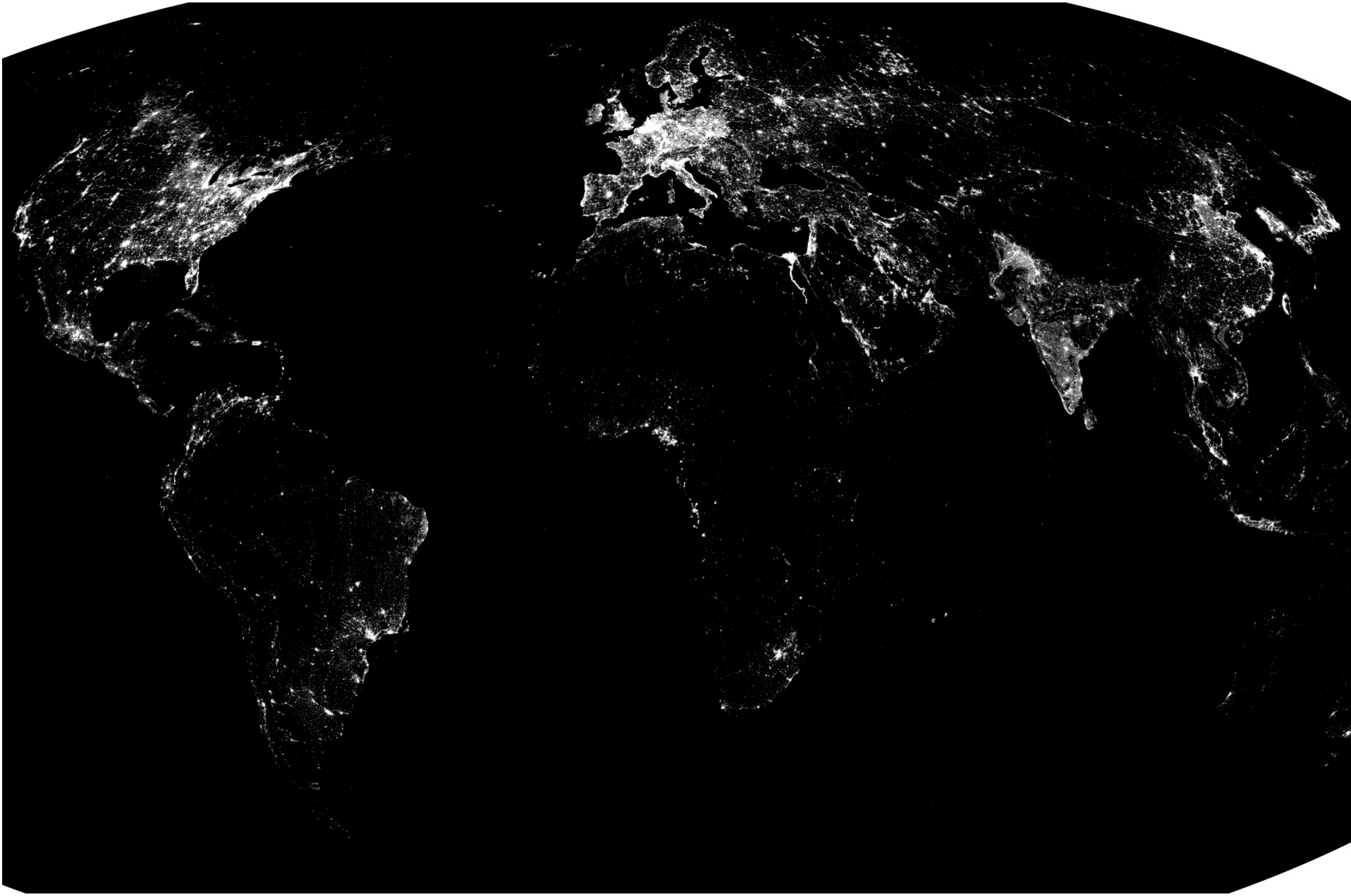
Earth's LAND surface (MODIS 2009)

IGBP type	Percent of Land Area
Evergreen Needleleaf forest	3.8
Evergreen Broadleaf forest	9.2
Deciduous Needleleaf forest	1.6
Deciduous Broadleaf forest	1.4
Mixed forest	4.3
Closed shrublands	1.7
Open shrublands	13.9
Woody savannas	9.2
Savannas	6.0
Grasslands	10.2
Permanent wetlands	1.3
Croplands	8.2
Urban and built-up	*0.5*
Cropland/Natural vegetation mosaic	5.4
Snow and ice	10.8
Barren or sparsely vegetated	12.5

Earth's LAND surface (Photo interpreted)

Type	Percent of Land Area
Croplands	6.9
Crop + Bare land crop. field	11.5
Forest	28.4
Grasslands	13.4
Shrublands	11.5
Waterbodies	3.6
Impervious areas	0.66
Bare lands	16.5
Snow and ice	12.8

Gong et al. 2013



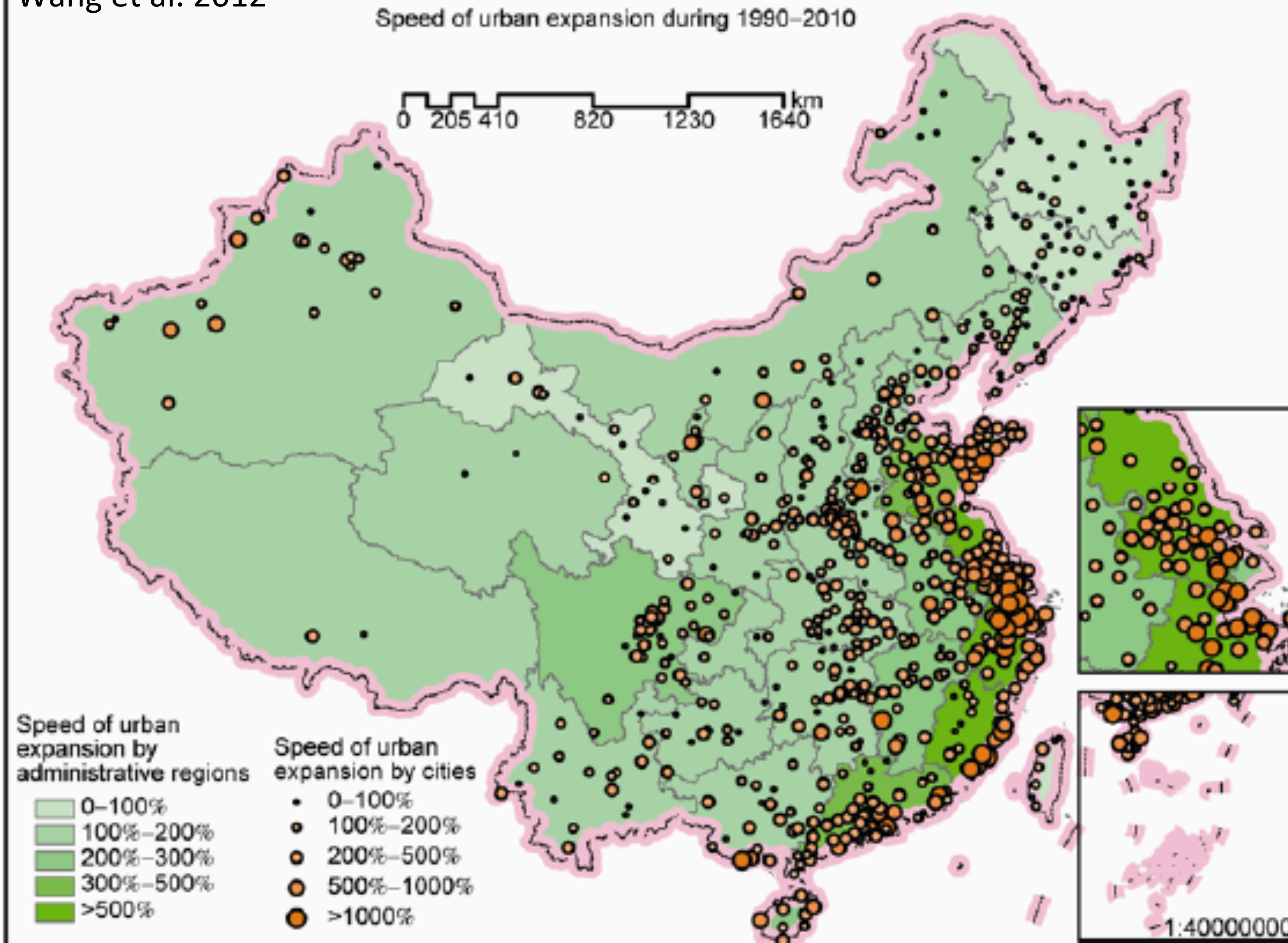
Earth's population & development

IGBP type	nightlights	population	percent
Water	0.04	23,338,664	0.3
Evergreen Needleleaf forest	1.88	36,018,188	0.5
Evergreen Broadleaf forest	0.43	136,801,104	2.0
Deciduous Needleleaf forest	0.28	1,381,437	0.0
Deciduous Broadleaf forest	3.69	26,474,294	0.4
Mixed forest	3.02	89,790,616	1.3
Closed shrublands	1.83	116,044,680	1.7
Open shrublands	0.49	170,196,672	2.5
Woody savannas	1.32	530,888,640	7.7
Savannas	0.63	188,525,456	2.8
Grasslands	1.10	266,599,104	3.9
Permanent wetlands	2.18	60,394,508	0.9
Croplands	7.39	1,938,534,400	28.3
Urban and built-up	*46.35*	*2,278,526,976*	*33.3*
Cropland/Natural vegetation mosaic	6.36	930,104,896	13.6
Snow and ice	0.02	356,065	0.0
Barren or sparsely vegetated	0.71	56,999,652	0.8
	max 63	6,850,975,352	

Geopolitical perspective

Country	Area (sq. km.)	Urban (sq. km.)	% Urban Area	% Urban Population
China	9,388,350	55,164	0.59	43.9
India	3,166,800	46,719	1.48	44.8
United States	9,470,940	19,813	0.21	23.8
Brazil	8,523,630	12,617	0.15	57.2
Japan	371,862	10,767	2.90	66.7
Indonesia	1,890,750	10,243	0.54	52.1
Russia	16,949,100	9,261	0.05	35.1
Germany	356,724	8,792	2.46	36.8
Vietnam	326,086	7,684	2.36	65.0
Bangladesh	138,505	7,189	5.19	50.2

Wang et al. 2012



Country scale statistics

	Percent Urban Population				
Development Group	*1950*	*1970*	*2011*	*2030*	*2050*
World………………	29.4	36.6	52.1	59.9	67.2
More developed	54.5	66.6	77.7	82.1	85.9
Less developed	17.6	25.3	46.5	55.8	64.1

United Nations. 2011. "World Urbanisation Prospects"

Effects

Surface Energy Balance

$$\Phi_{\mathrm{ATM}} - \Phi_{\mathrm{Earth}} + (1 - \rho_\lambda)(\Phi_{\mathrm{Direct}} + \Phi_{\mathrm{Diffuse}}) - LE - H - G + Q = 0$$

Φ_{ATM} =longwave downward radiance

Φ_{Earth} = longwave upward radiance

ρ_λ= surface reflectance at wavelength λ

Φ_{Direct} = shortwave direct solar radiance

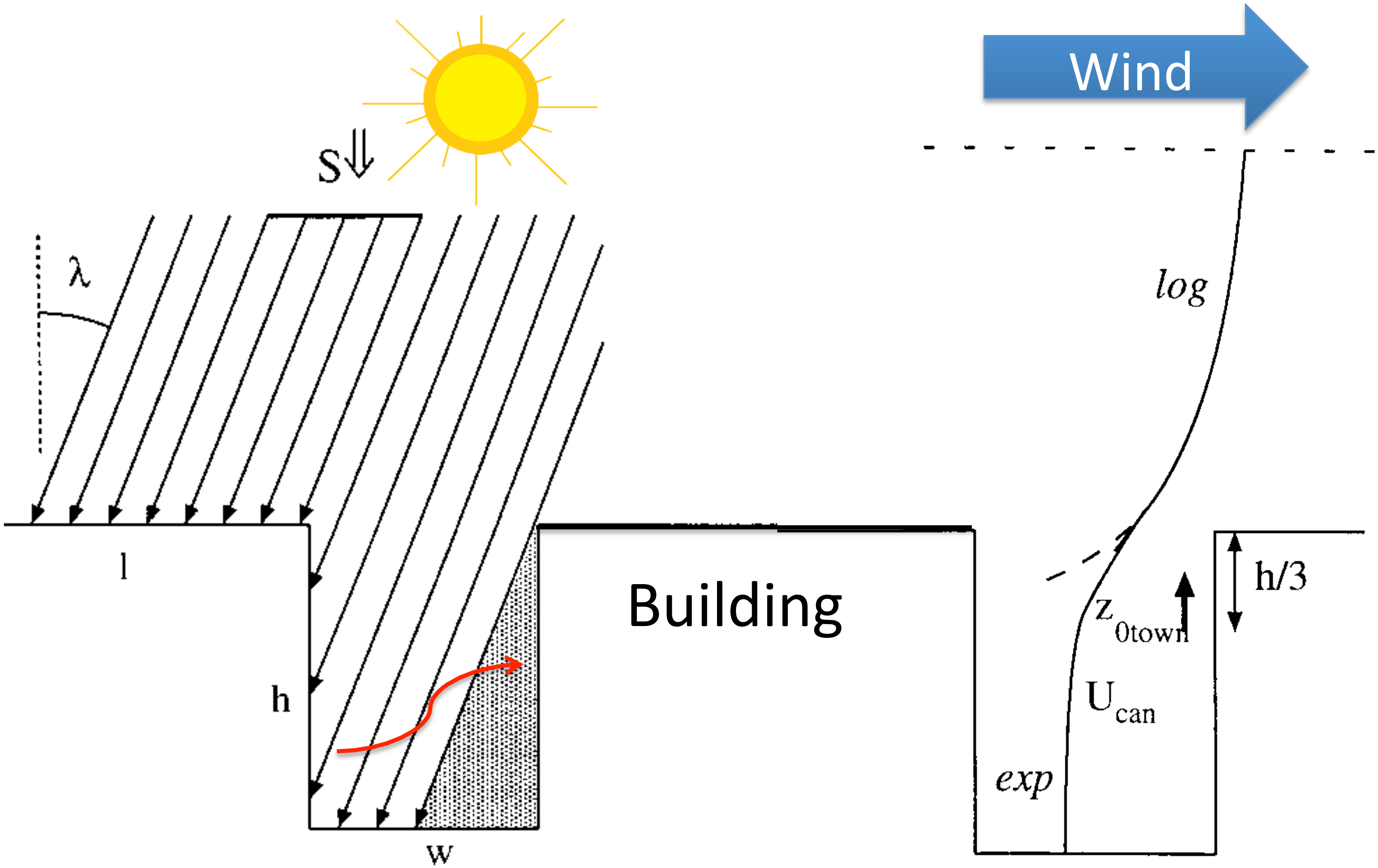
Φ_{Diffuse} = shortwave diffuse solar radiance

LE = latent heat loss from surface

H = sensible heat loss from surface

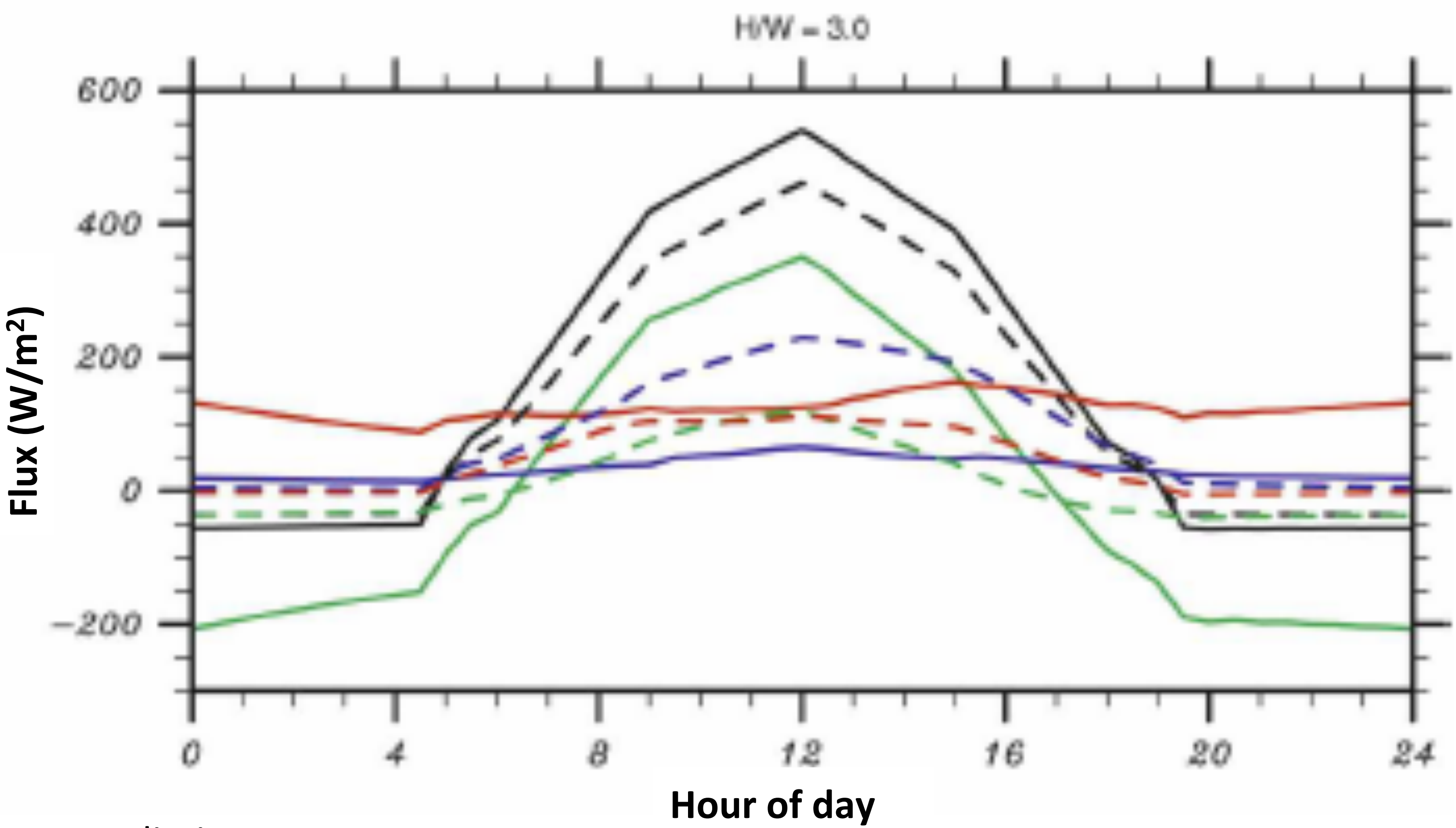
G = heat flux to ground, buildings, etc. (storage)

Q = anthropogenic heat generation



Masson. 2000

Modeled Heat Flux



Net radiation
Sensible heat
Latent heat
Storage

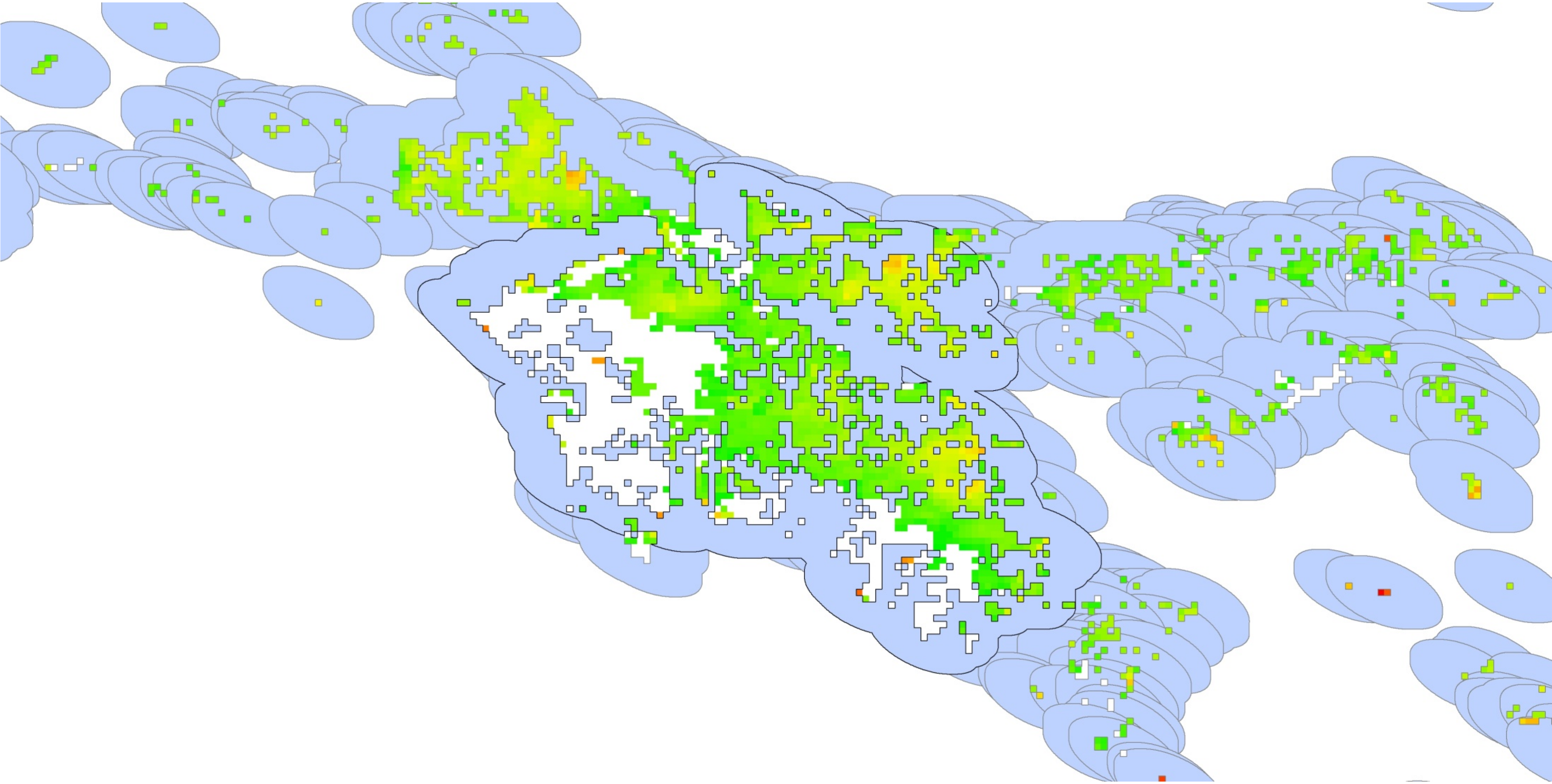
Urban
Rural

Oleson et al. 2008

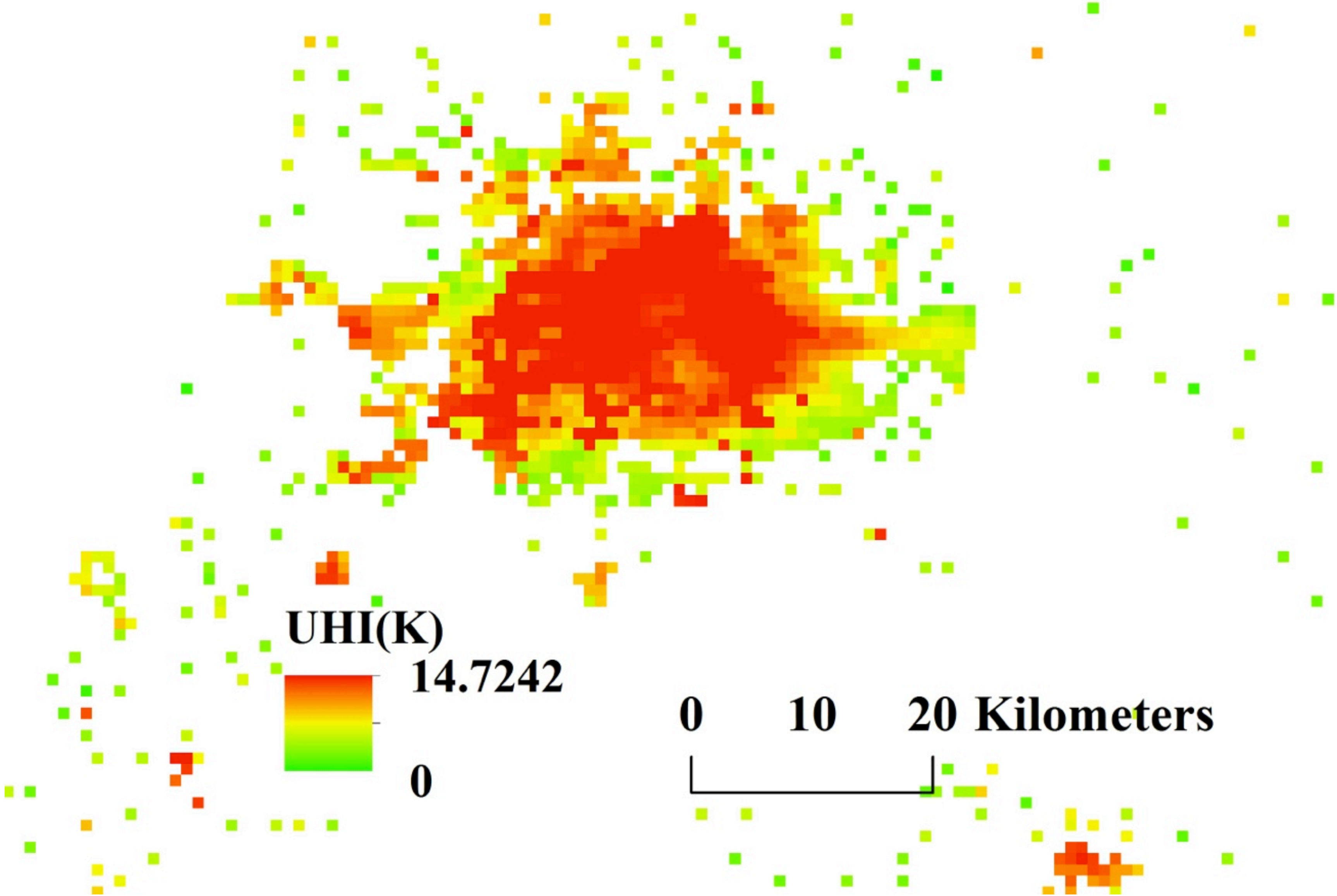
Surface Urban Heat Differential: Methods of Measurement

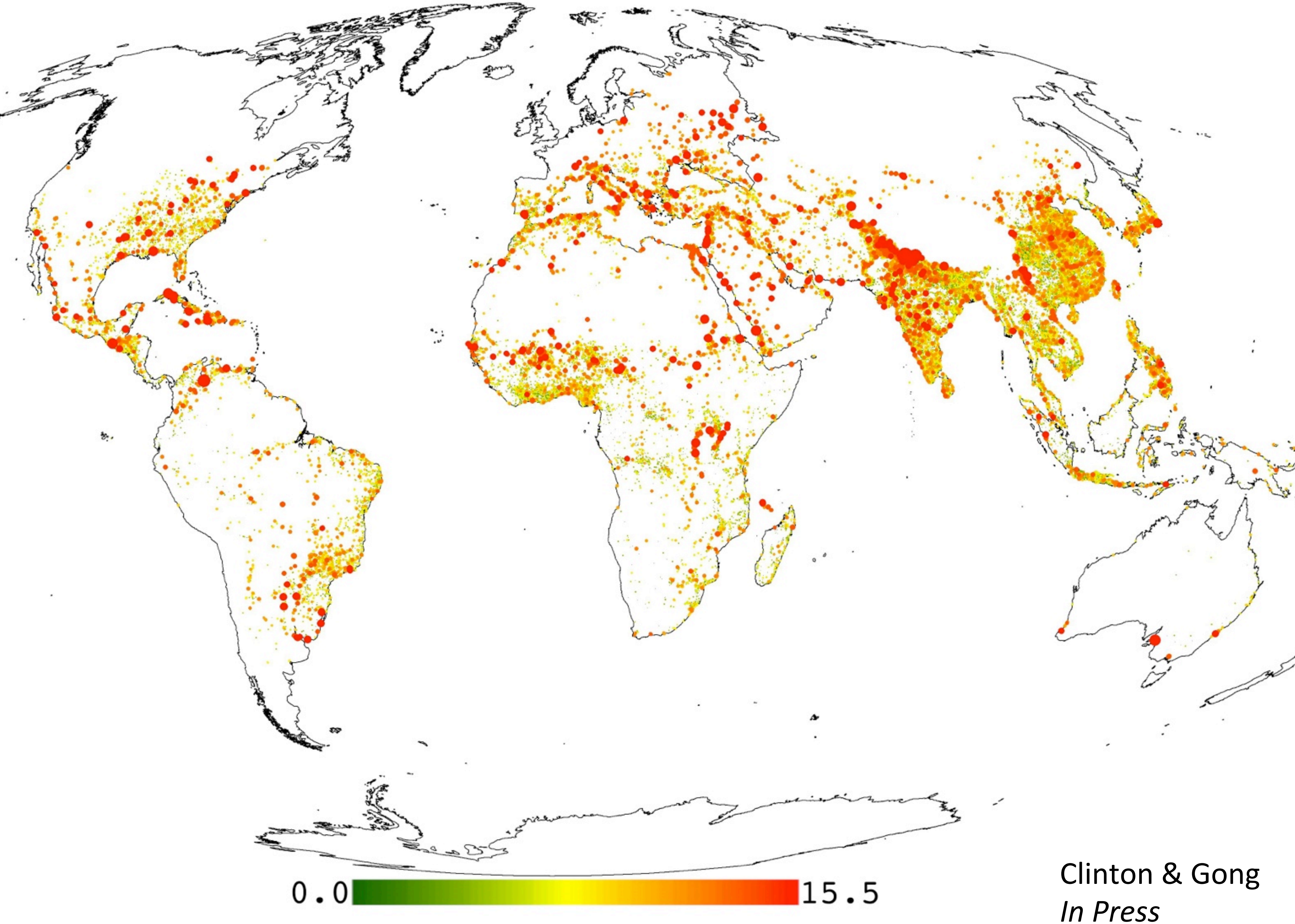
- Annual time series (2010) of MODIS (Terra and Aqua) land surface temperature, MOD11, MYD11
- Landscan “multi-story structure urban” urban area
- Annual time series (2010) of MODIS (Terra) enhanced vegetation index (EVI), MOD13
- Landscan population data

Heat differentials



Beijing Surface Urban Heat Island Cooling Degree Days





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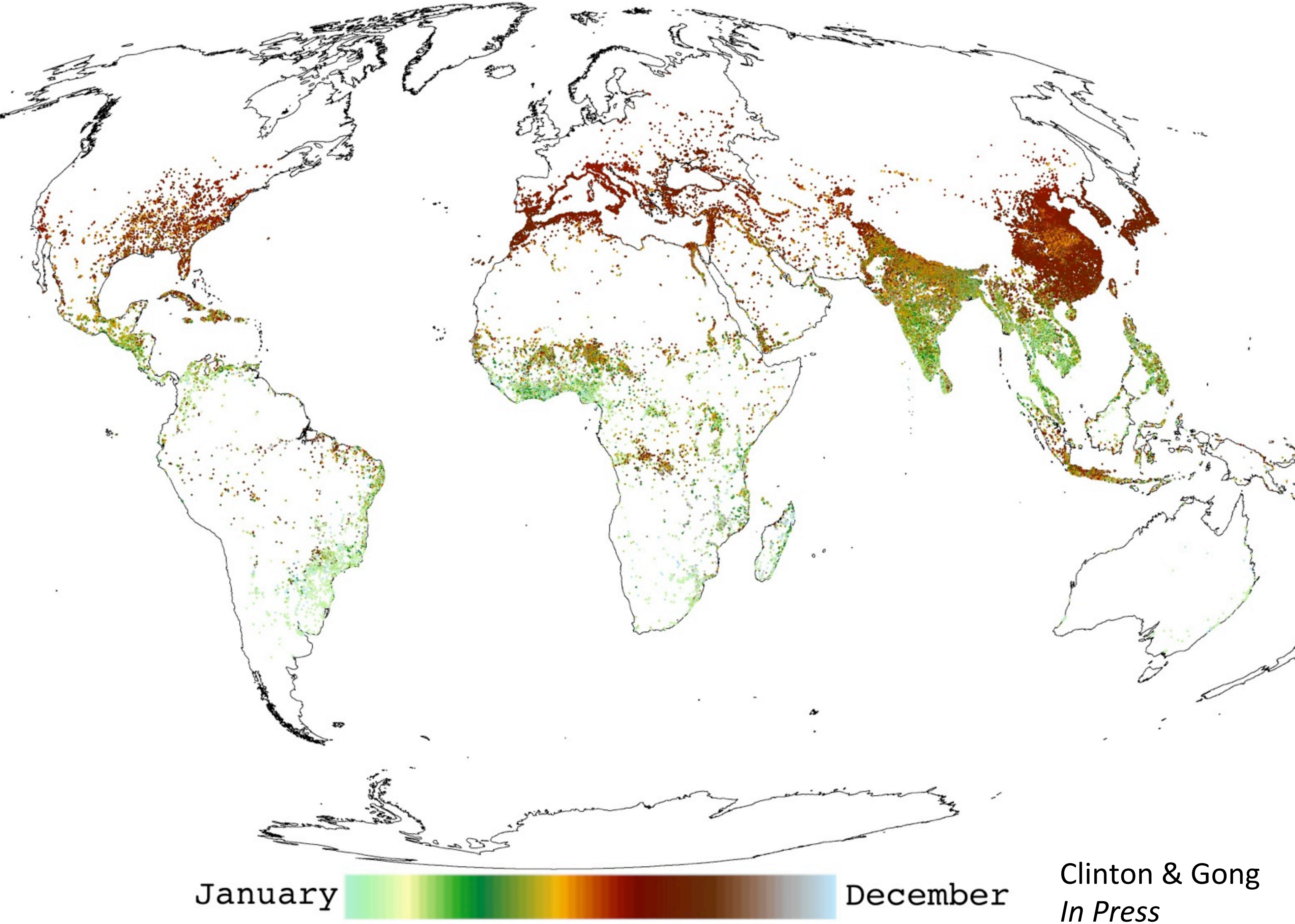
In Press



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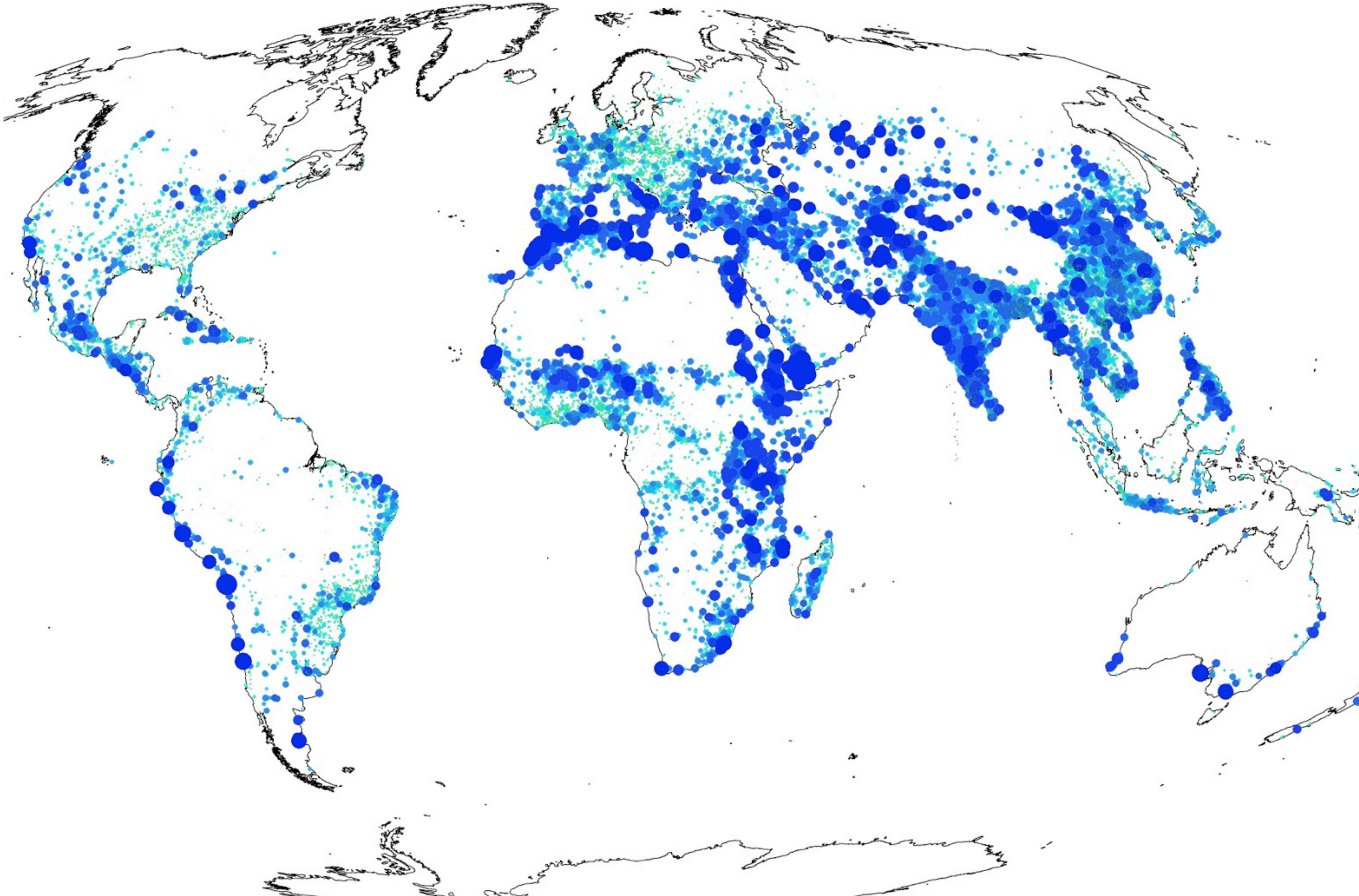

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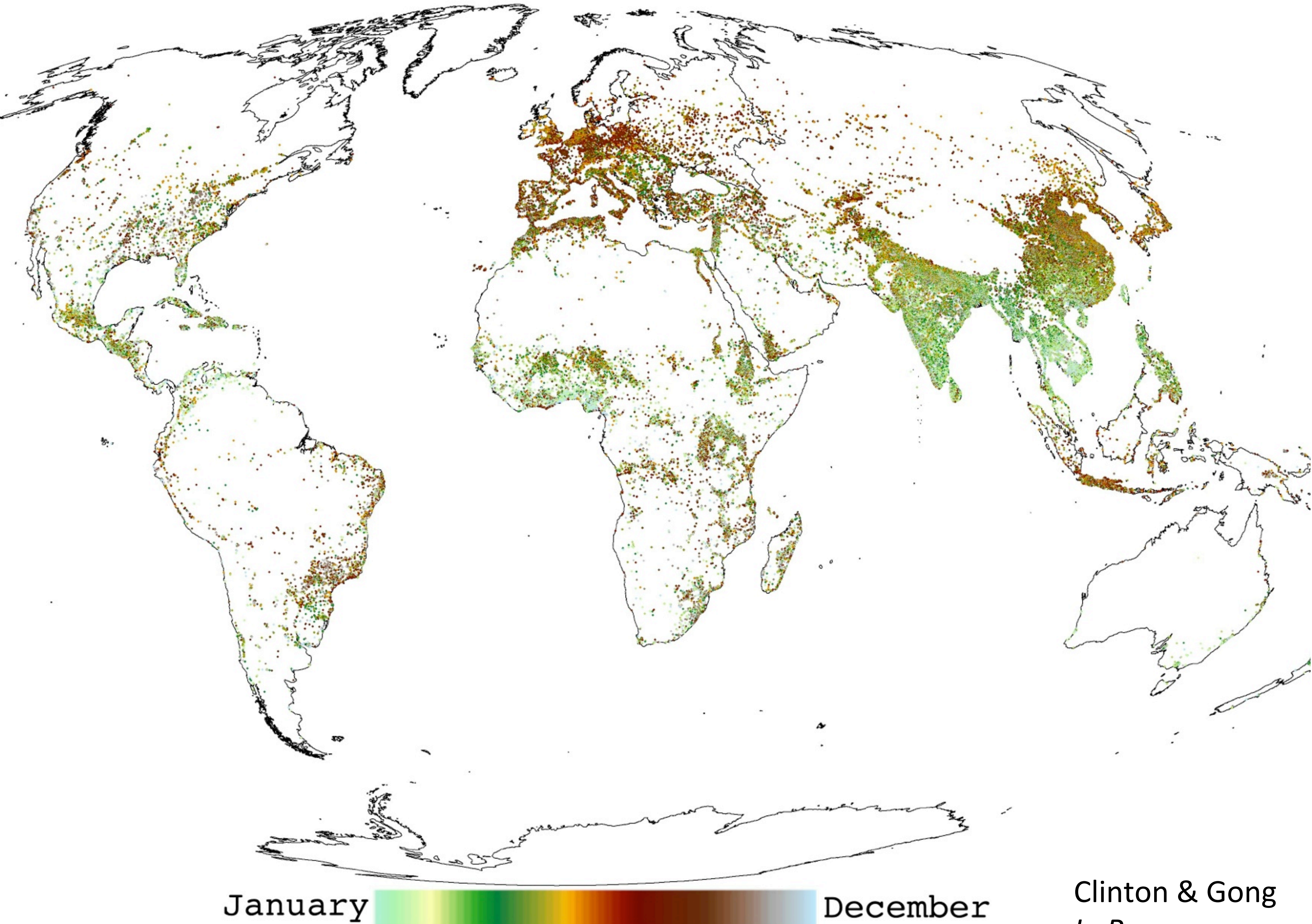

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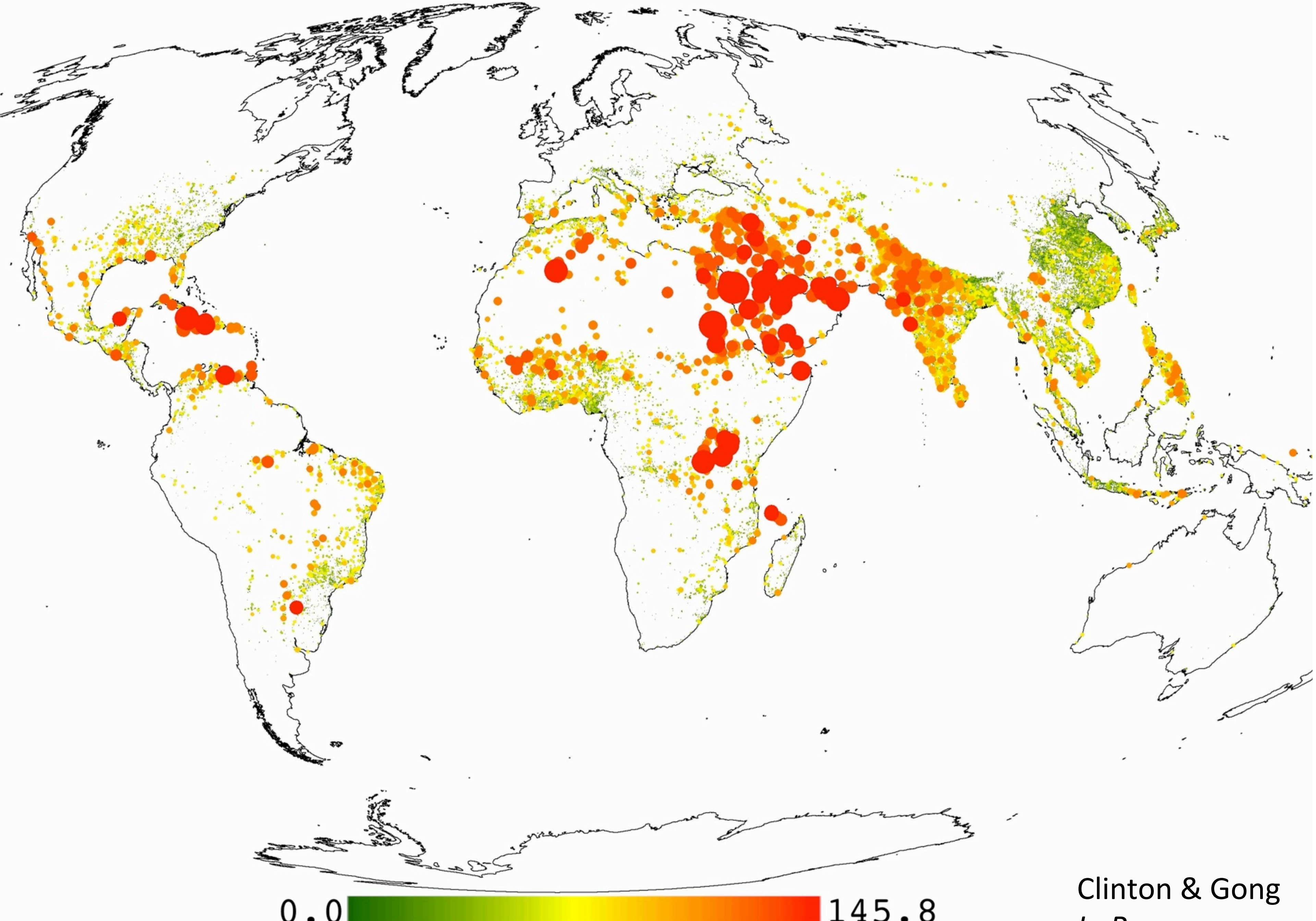

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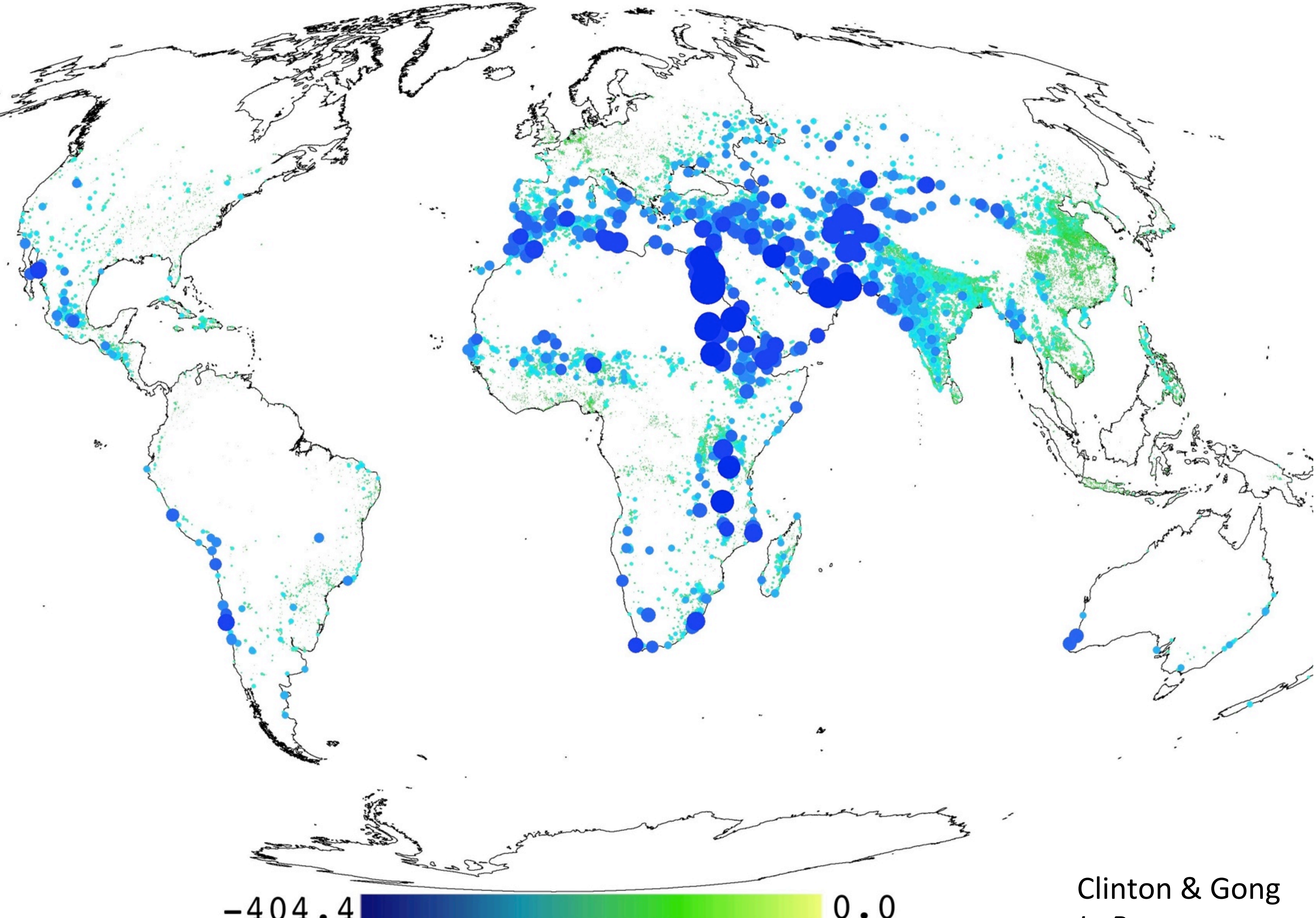

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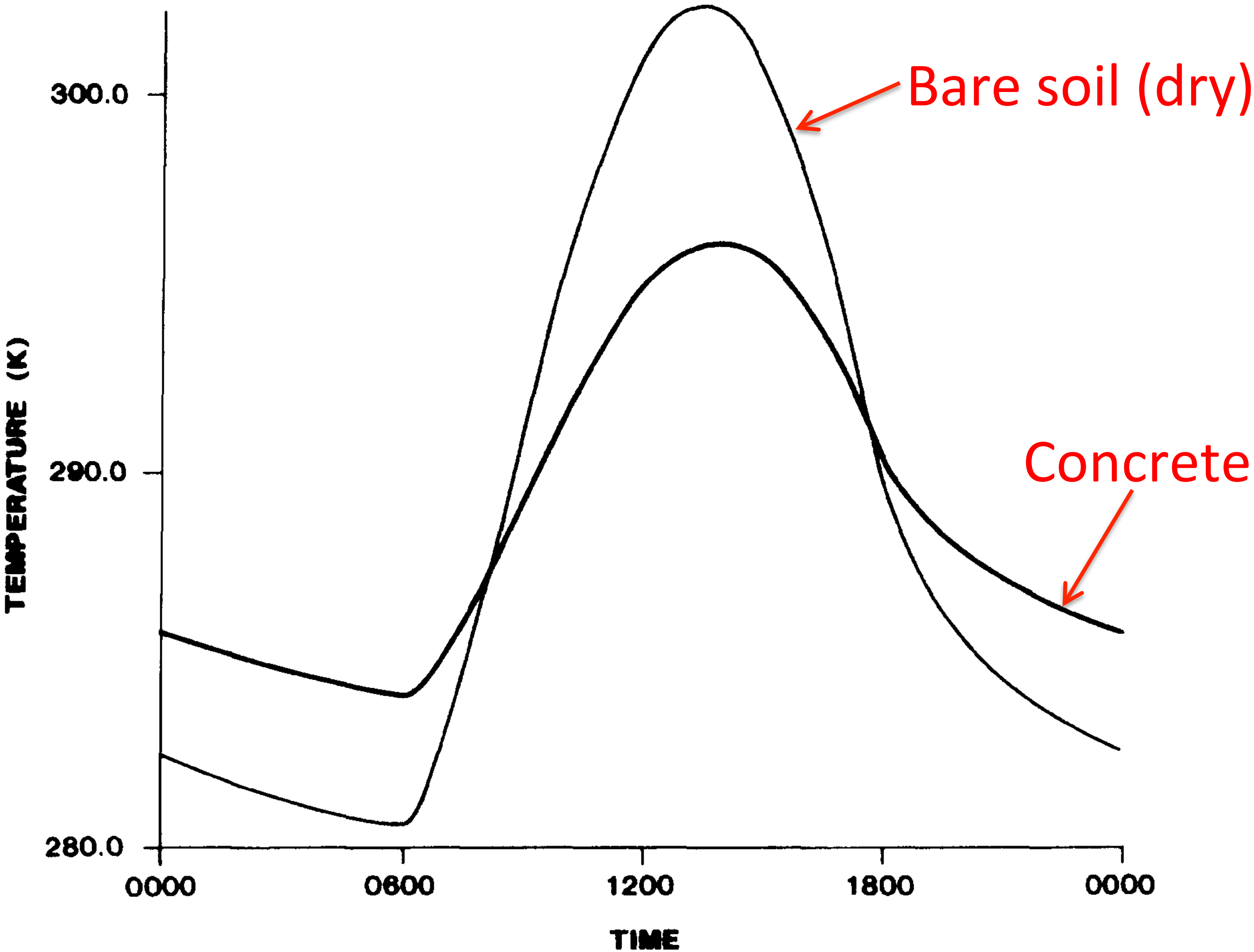
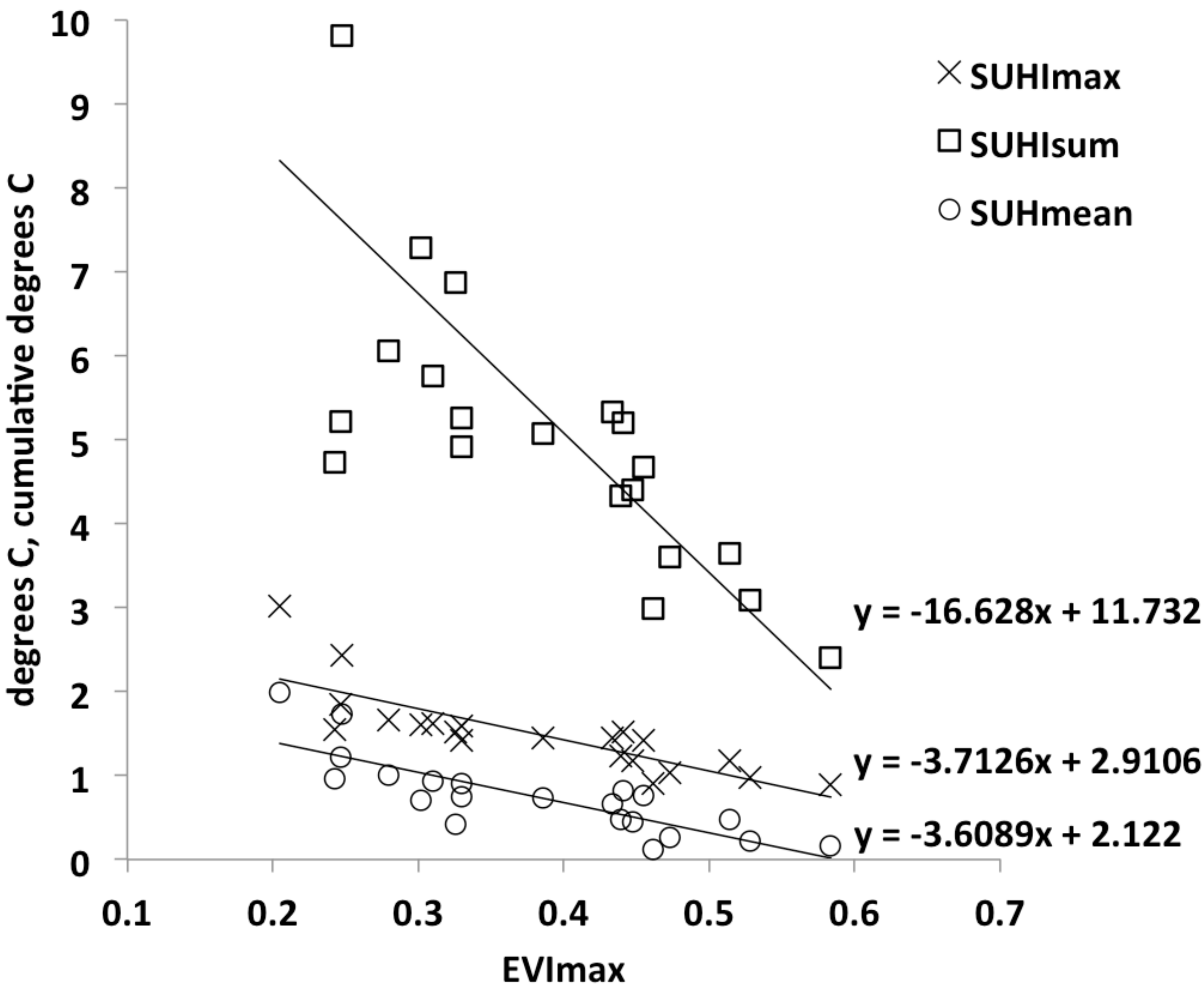
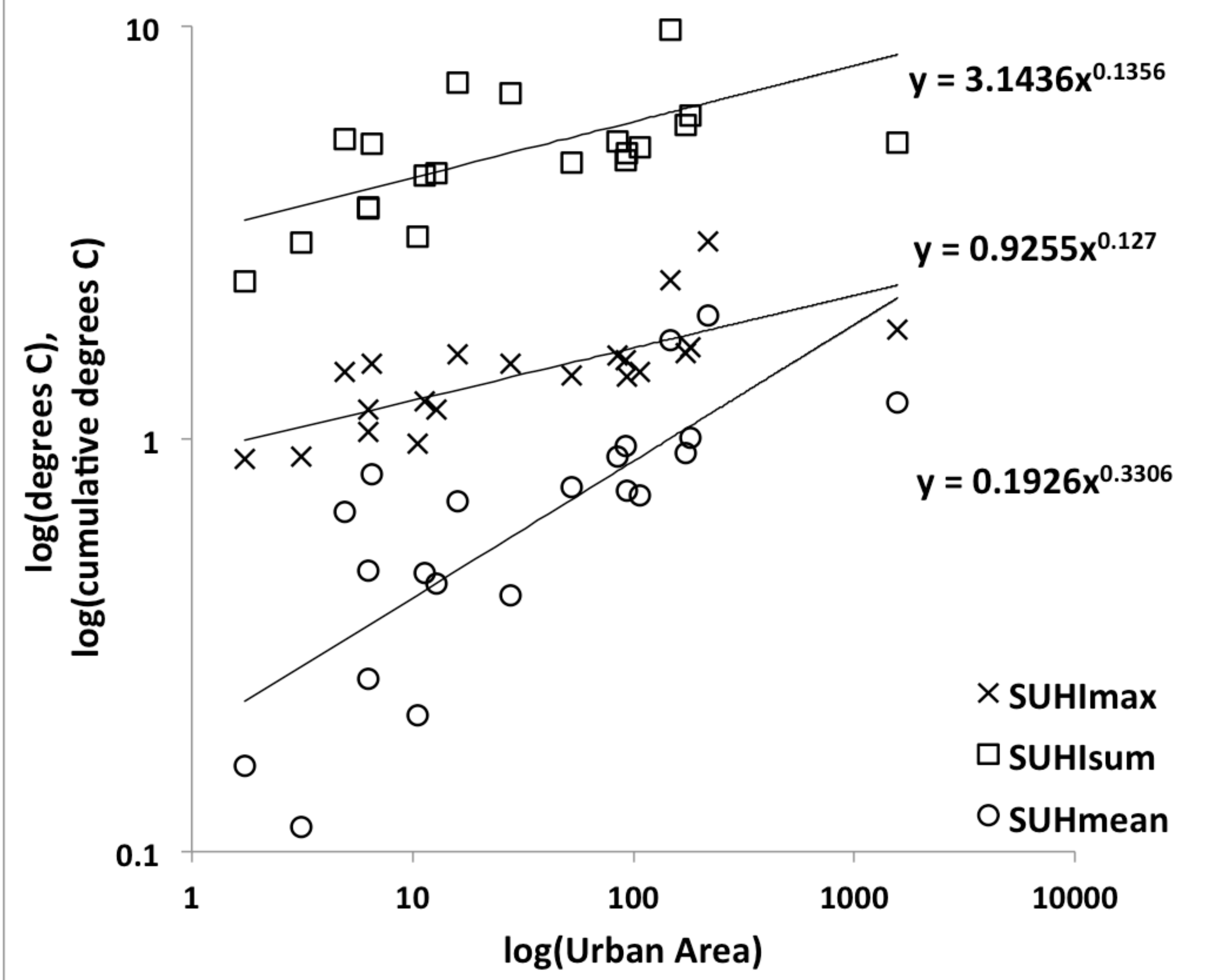
		Nighttime $SUHI_{max}$		Daytime $SUHS_{min}$		Nighttime $SUHI_{sum}$		Daytime $SUHS_{sum}$	
Landcover	*n*	*annual*	*cdd*	*annual*	*cdd*	*annual*	*cdd*	*annual*	*cdd*
unclassified	3108	1.6	1.2	-2.0	-1.9	9.2	3.9	-9.6	-8.8
barren	12102	2.4	2.1	-3.6	-3.6	24.8	13.8	-47.6	-47.7
CS	5965	1.8	1.6	-2.3	-2.3	8.3	4.3	-12.1	-11.3
CM	76156	1.8	1.3	-1.9	-1.8	8.8	4.6	-6.1	-6.0
cropland	195013	2.1	1.3	-2.0	-1.9	12.7	4.6	-9.4	-9.4
DBF	2945	1.8	1.4	-1.7	-1.5	7.5	3.4	-4.1	-4.0
DNF	165	4.5	1.2	-1.1	-0.8	34.4	5.1	-2.1	-1.2
EBF	29035	1.7	1.5	-1.6	-1.6	6.9	5.3	-3.6	-3.4
ENF	5483	2.6	1.2	-1.6	-1.2	13.4	2.4	-3.8	-2.7
grassland	24161	2.6	1.8	-2.7	-2.8	18.4	6.5	-15.3	-16.0
MF	35968	2.3	1.7	-1.6	-1.4	10.9	4.2	-3.6	-2.7
OS	19738	2.2	1.9	-3.1	-3.1	17.7	8.6	-25.0	-25.7
savanna	11443	1.7	1.7	-2.6	-2.6	9.6	6.2	-10.9	-10.8
snow	13	4.9	0.5	-1.0	-1.0	60.5	1.0	-2.5	-2.9
urban	35778	1.9	1.6	-1.8	-1.9	7.7	4.4	-5.8	-6.7
wetlands	12701	1.4	1.2	-1.8	-1.8	5.3	4.2	-6.2	-5.8
WS	53464	1.7	1.4	-1.9	-1.8	8.3	4.3	-7.3	-6.8



Carnahan and Larson. 1990. *RSE*.



SUHImax
SUHIsum
SUHmean
y = -16.628x + 11.732
y = -3.7126x + 2.9106
y = -3.6089x + 2.122
degrees C, cumulative degrees C
EVImax
0
1
2
3
4
5
6
7
8
9
10
0.1
0.2
0.3
0.4
0.5
0.6
0.7



10
1
0.1
1
10
100
1000
10000
y = 3.1436x^0.1356
y = 0.9255x^0.127
y = 0.1926x^0.3306
log(degrees C),
log(cumulative degrees C)
log(Urban Area)
SUHImax
SUHIsum
SUHmean

Best predictors (causative factors?)

Urban area

SUHI$_{max}$		Daytime SUHS$_{min}$				Nighttime SUHI$_{sum}$				Daytime SUHS$_{sum}$				UH$_{night}$				UH$_{day}$			
CDD		*annual*		*CDD*		*annual*		*CDD*		*annual*		*CDD*		*annual*		*CDD*		*annual*		*CDD*	
MSSU	GLA14	MSSU	GLA14	MSSU	GLA14	MSSU	GLA14	MSSU	GLA14	MSSU	GLA14	MSSU	GLA14	MSSU	GLA14	MSSU	GLA14	MSSU	GLA14	MSSU	GLA14
2.3	2.7	4.9	5.7	4.1	6.0	2.3	3.9	2.7	2.1	3.7	5.1	3.7	6.0	1.9	2.7	1.7	2.6	1.7	2.4	1.7	2.7
4.1	5.9	2.4	2.0	2.6	3.3	2.4	3.1	3.0	3.3	1.9	1.7	1.6	1.4	4.1	5.7	4.3	7.1	3.0	4.1	3.0	4.3
4.6	9.3	4.0	4.7	3.4	4.0	3.0	3.6	4.3	6.3	3.1	3.9	2.7	4.6	4.4	5.9	4.1	4.4	3.9	5.7	3.6	4.3
1.7	1.7	4.1	3.7	3.4	3.1	3.6	2.7	2.1	1.9	3.6	5.9	3.7	5.6	1.7	1.7	2.0	2.0	3.4	4.3	3.7	4.3
6.4	9.9	5.1	6.0	5.3	8.6	5.3	9.1	5.9	10.6	4.4	4.7	4.4	3.0	6.1	10.3	5.6	9.7	5.6	9.4	5.4	9.1
6.3	7.1	7.9	9.3	7.9	11.4	6.7	9.4	5.7	5.1	6.9	11.6	6.6	11.4	5.9	8.9	6.6	9.3	6.4	10.9	6.9	10.0
3.6	4.1	5.1	4.6	4.7	4.7	4.7	4.9	4.3	5.0	4.4	3.3	5.3	4.9	3.9	4.3	3.7	4.0	4.0	4.0	3.7	5.0
	6.3		9.6		8.4		7.9		7.0		7.6		7.7		6.3		6.6		6.3		6.3
	11.4		9.6		8.7		11.1		11.4		10.0		10.1		10.6		11.3		11.3		11.3
	6.6		9.7		10.6		7.6		8.1		8.7		8.1		7.3		6.9		6.6		6.9
	10.0		9.6		7.7		11.1		11.7		11.0		11.1		11.1		10.6		10.9		10.7
	7.9		7.9		7.4		8.0		9.3		8.6		8.9		7.7		8.0		7.7		7.6
	8.1		8.7		7.0		8.6		9.1		9.0		8.1		8.6		8.6		7.4		8.6

EVI maximum

BOSCO VERTICALE

Stefano Boeri's "metropolitan reforestation" concept

California Academy of Science,
San Francisco, CA USA

Renzo Piano's concept of a "living roof"

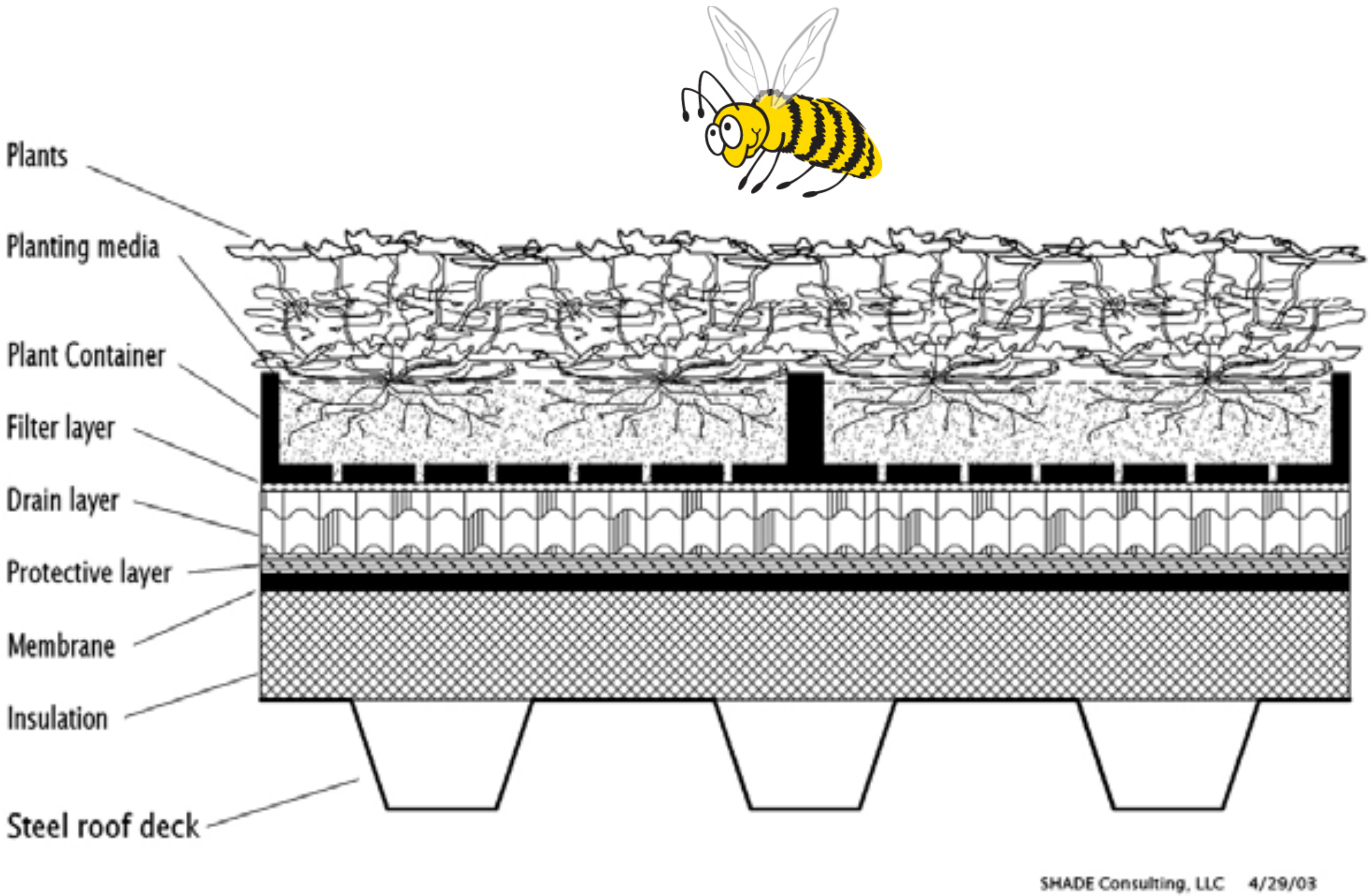
“Asian Cairns” concept for Shenzhen. Vincent Callebaut Architectures

Tongyang town, Hubei, China

Opportunity cost?

Computing the benefits

- Landscan "multi-story structure urban" urban area
- Landscan population data
- FAO agricultural productivity data by country
- PERSIANN daily rainfall data
- WorldClim monthly average climate data
- Published rates for ecological services such as nitrogen sequestration, biocontrol and pollination

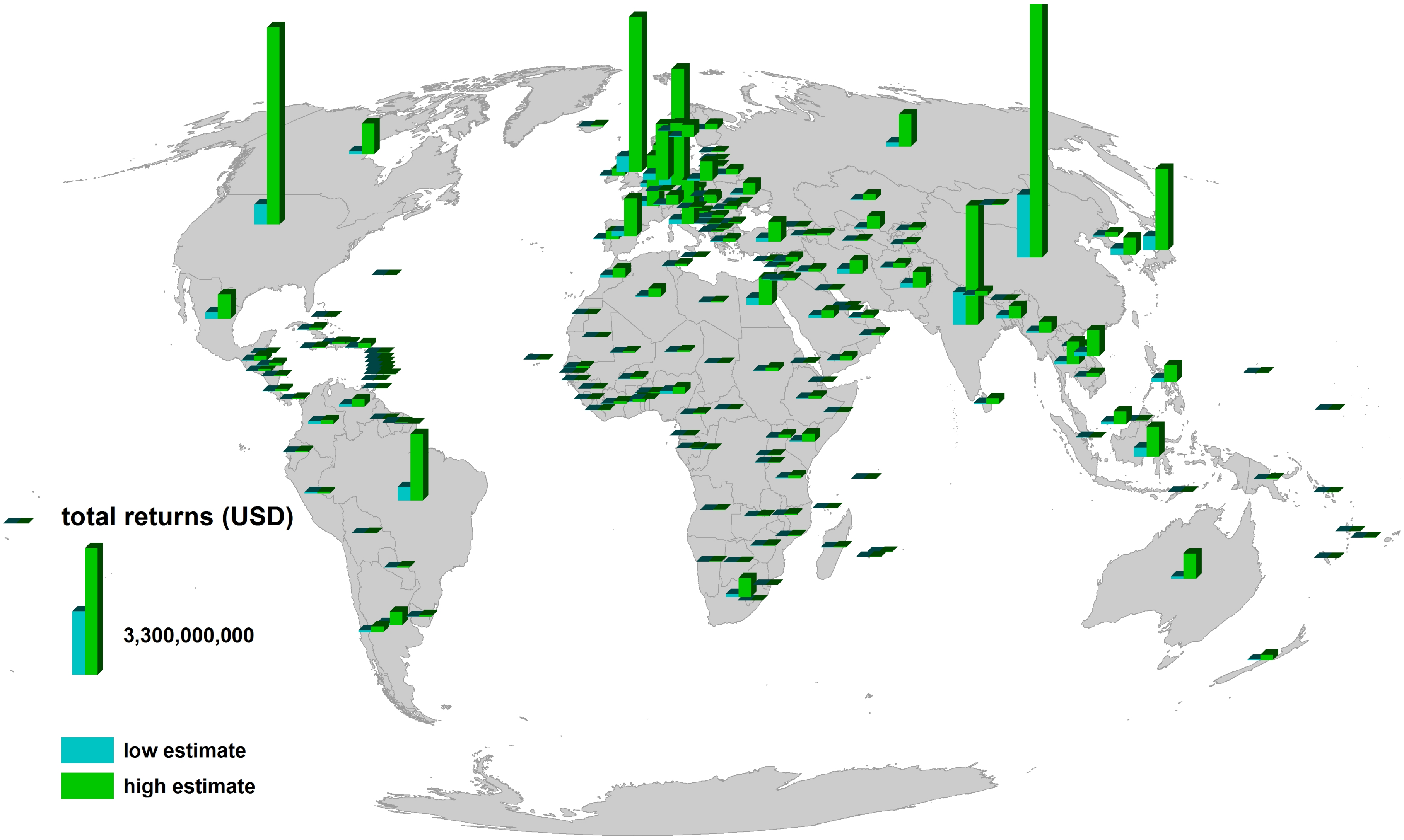


Wark and Wark. 2003.

Urban Cultivation: potential benefits

Service	Low Estimate	High Estimate
Agriculture (USD)	$8,680,496,417	$50,875,684,508
Nitrogen Fixation (USD)	$107,598,732	$493,821,077
Biocontrol (USD)	$32,100,058	$147,456,360
Pollination (USD)	$18,727,291	$86,026,579
Energy savings (kWhrs/year)	14,429,132,444	17,266,236,168
Stormwater avoidance (m^3)	5,979,702,495	29,189,169,387

Global Urban Agriculture potential



There is no conclusion

- Urbanization is ongoing, and cities will agglomerate together, making ever larger “megalopolises” (Small et al. 2011)
- The urban population will increase (UN 2011)
- The process affects regional climate (Kalnay and Cai, 2003; Yang et al., 2011; Zhang et al., 2013)
- Cities make people sick (Frumkin 2001, Srinivasan et al. 2003, Gong et al. 2012)
- Vegetation makes people happy (Hartig et al. 2003, Barton and Pretty 2010, Kaplan 1995, Berman et al. 2008)
- Why should we live in a “biologically impoverished” environment?

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Thank you!

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