UGEC POLICY REPORT #5

Urban Remote Sensing and Urban Growth Forecasting Workshop Report | December 2011

Urbanization and Global Environmental Change
AN IHDP CORE PROJECT

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Urban Remote Sensing (URS) and Forecasting Urban Land-Use (FORE) Workshops: Common Ground and Targeted Opportunities

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Cities offer opportunities unmatched by their rural counterparts in terms of being hubs for economic growth, community building, and cultural creativity and expression. Furthermore, by concentrating human activities in urban centers, there is also the opportunity to protect habitats in outlying areas and increase the efficiency of municipal services such as power, water, sanitation, and education. In contrast, cities can also result in increased poverty, crime, social detachment and pollution. And while it is idealistic to think that the environmental impact of cities is local, the footprints of cities are extensive and can lead to widespread environmental degradation. These opportunities and problems represent key challenges for investigators and planners who simultaneously intend to promote improved urban living but in a way that supports long-term growth and environmental and social sustainability (Seto et al., 2010).

Workshop motivation and organization

Two workshops focusing on urbanization and its impacts were held jointly at Arizona State University (ASU) in April 2011- a workshop on urban remote sensing (URS), funded by the U.S. National Science Foundation (NSF) and a workshop on forecasting urban land-use change (FORE), funded by the National Aeronautics and Space Administration (NASA) and organized by the Urbanization and Global Environmental Change (UGEC) project. The workshops were held jointly to address the common goal of understanding urbanization through four parallel themes running throughout both workshops: data, applications, scale and case studies. The application discussion involved identifying how remotely sensed data and land-use forecasting models could be widely used by decision-makers and other stakeholders. The aim of the scale discussion was to define what is meant by scale and yet to recognize that it is an unsolvable but manageable issue. The data discussion aimed to understand the kind of data that are available, which data are needed, and how they can be accessed. Finally, the case studies discussion focused on alternative ideas on generating more case studies or developing a theoretical framework for comparing cities.

The workshops hosted approximately 35 academics and practitioners from 13 countries and five continents. Participants were asked to prepare short or medium length summary documents on the current state-of-knowledge on one of the four themes. These white papers were compiled and disseminated prior to the workshop to facilitate conversations focused on moving forward rather than on what has been done. On site, we had minimal presentations and numerous active conversations with moderators to guide the discussion and rapporteurs to record key points. Each morning, we distributed highlights from the previous day to energize the day’s discussion.


Workshop participants

The goal of this article is to sustain the momentum that emerged from the two workshops and extend opportunities to a larger researcher and practitioner community. Below we focus on how the dynamics between the two workshops emerged in common ground, diverging interests, and steps to move forward.

Common ground

Common ground emerged between the two workshops in each of the four themes. In particular, four common questions and issues transpired:

1. **The need to improve accessibility and usage by non-expert users**. URS participants hypothesized that uptake by users outside of the remote sensing community remains low because there is a view that accessing and using remotely sensed products is difficult and requires expert use of specialized software. FORE participants questioned the policy-relevance of models and discussed disconnect between spatial models of urban growth and economic models of urban development. Although both groups speculated on different causes, the common conclusion is that there is a need to facilitate wider use of data and models through open-source, web-based data and tools. Both groups agreed that communication becomes a central tool for moving forward.

2. **The need to explicitly examine the range of scales in analysis**. Both workshops defined scale broadly, converging on spatial, temporal, governance, and economic scales. Each context includes grain size and spatial extent. URS added spectral scale to this list, to include the range of spectral information in the electromagnetic spectrum with regards to remotely sensed data. Beyond the basic definitions, however, the problems associated with scale and the possible solutions to them varied between the two groups. These differences will be discussed in the 'Diverging interests' section below.

3. **The need to increase data availability and accessibility**. Gaps in knowledge on data availability and accessibility emerged frequently throughout the workshop. Both groups linked data availability to the prior discussion on

scale, recognizing that data are not always available at all scales. Furthermore, there was consensus between the groups that data, which exist in ‘silos’ and only accessible with expert knowledge, is needed for decision-making purposes. The data needs are also consistent between the groups. Data archives that store longitudinal data are needed to provide temporal information at as-detailed-as-possible spatial scales. There was a shared sentiment that technology associated with preprocessing, geo-rectification, data fusion, standardization, networking, and validation provides key solutions to accessibility and therefore usability of needed data.

4. **The need to develop an urban typology and framework to facilitate comparative studies across cities**. As a research community, we need to continue to study regions in depth and to create conceptual demonstrations of modeling efforts, but there is also the need for a theoretical framework to tie case studies together. We need to build a typology of cities to capture their complexity but have this built around a more theoretical framework. Furthermore, participants suggested that we do not start from scratch but rather leverage existing work to move forward more efficiently. For example, Fink (2011) proposed modeling urban efforts after the human genome project.

Diverging interests

In addition to the common ground just described, notable differences emerged during the joint discussions. The mixture of academic and practitioners as well as the different overarching objectives led to different emphases. This diversity provided additional opportunities to move forward.

During the ‘application’ discussions, URS questioned why remotely sensed data are not widely used for planning and policy-making. They speculated that one problem is data and software are perceived to be expensive to acquire and difficult to use. Participants pointed out that a non-solution would be to wait for a Google-like company or a NASA-type initiative to take the lead. Currently, such an effort is not part of the Google business model and is not a NASA mandate. Instead, this group suggested that a possible solution would be to develop and promote open-source web solutions to data access and interpretation. In contrast, the FORE group similarly questioned why planners and practitioners underutilize land-use forecasting models. They speculated that one reason is that there are unique problems faced by decision makers in different locations and therefore different solutions are needed for models.

These different conversations led both groups to discuss how more case studies are needed but within a unifying theoretical framework. Case studies could be developed to illustrate how data that are free to acquire and easy to manipulate can provide comparative information across temporal and spatial scales. The theoretical framework would be built around how policy can affect real-world outcomes. For example, vegetation data in the form of a Normalized Difference Vegetation Index (NDVI) can be quantified from medium resolution, free data over a span of multiple years. These data could be used to model and analyze the impact of landscaping policies and the urban heat island effect.

Steps to move forward

Four critical steps can move the urban research agenda forward with an overarching theme that involves broader engagement and increased communication.

1. There is a need for academic researchers, model developers, and decision-makers to work together on urban issues so that the data we acquire and the analyses we perform are policy relevant.
2. The study of urban areas is unique in that it offers opportunities for both theoretical and applied work. Yet, there is a noticeable gap between empirical research and theory development. How do the myriad of urban remote sensing and modeling studies contribute to advancing fundamental knowledge of urbanization, sustainability, and how the Earth works? As a research community, we need to move closer towards bridging the empirical with the theoretical. Otherwise, we risk the danger of diving too deeply into the nuances of our algorithms and models at the expense of progress on 'the big questions'.
3. There is a considerable amount of data and information widely and (often) freely available. Although sometimes the data are awkward to acquire, there is an opportunity to overcome the limitations imposed by scale and data costs. We need to overcome the inertia to tap into them, be it crowd sourcing data or epidemiological data.
4. Research foci are becoming increasingly narrow in scope, which may be limiting our ability to address our problems. It may be time for academics to re-assess: are we asking the most salient questions for human well-being?

This article described the planning strategy, the unifying challenges and solutions, and the final engagement and outcomes associated with the joint workshop event. Our goal was to host an event that made the two groups more than the sum of the individual parts. We aim for continued efforts among the group of workshop participants as well as inviting other researchers and practitioners in urban remote sensing and forecasting urban land-use change to join us.

References

Fink, J. (2011). The case for an urban genome project: a shortcut to global sustainability? *The Bridge*, *4*(1), 5-12.

Seto, K.C., Sánchez-Rodríguez, R., & Fragkias, M. (2010). The new geography of contemporary urbanization and the environment. *Annual Review of Environment and Resources*, *35*(1), 167-194. doi:10.1146/annurev-environ-100809-125336. http://www.annualreviews.org/doi/abs/10.1146/annurev-environ-100809-125336

The Dimensions of Global Urban Expansion, 2000–2050[1]

Dr. Shlomo Angel, 11 March 2011

Accra, the capital of Ghana, offers a startling example of urban expansion (figure1). Between 1985 and 2000, the city's population grew from 1.8 to 2.7 million, a 50 percent increase, while its urban land cover expanded from 13,000 to 33,000 hectares, a 153 percent increase. Urban land cover in Accra grew more than twice as fast as its population.

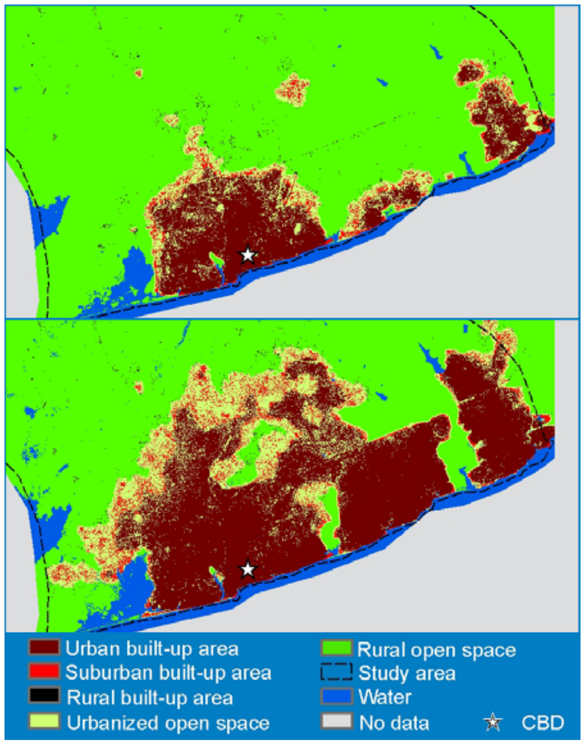

Figure 1: Expansion of the Built-up Area of Accra, Ghana, 1985–2000

We examined the growth rates of the urban population and the urban land cover in the global sample of 120 cities between 1990 and 2000. Population growth averaged 1.60 percent per annum, and land cover growth averaged 3.66 percent per annum. The difference between them averaged 2.06±0.32 percent. Thus, as in Accra, urban land cover in all 120 cities grew on average at more than double the growth rate of the urban population. At these rates, the world's urban population will double in 43 years and the world's urban land cover will double in only 19 years.

The rapid growth of urban land cover is by no means a recent phenomenon, as clearly shown in the historical expansion of Bangkok, the capital of Thailand, during the past 150 years (figure 2). Bangkok increased its urbanized area from 580 hectares in 1850 to 133,515 hectares in 2002. In 1944, for example, its urbanized area comprised 8,345

[1] This note is an excerpt (Chapter 4) from a recent Policy Focus Report by the Lincoln Institute of Land Policy titled *Making Room for a Planet of Cities*, co-authored by Shlomo Angel, Jason Parent, Daniel L. Civco and Alejandro M. Blei. Online at https://www.lincolninst.edu/pubs/dl/1880_1195_Angel%20PFR%20final.pdf. A detailed version of this chapter is now under peer review in *Progress in Planning*, based on a working paper titled "A Planet of Cities: Urban Land Cover Estimates and Projections for All Countries, 2000–2050", online at http://www.lincolninst.edu/pubs/1861_A-Planet-of-Cities.

hectares, a 14-fold increase over its 1850 area. The city then doubled its area in 15 years (1944–1959), doubled it again in 9 years (1959-1968), doubled it again in 10 years (1968–1978), and doubled it yet again in 24 years (1978–2002). In other words, the urbanized area of Bangkok increased 16-fold between 1944 and 2002, at an average growth rate of 4.8 percent per annum.

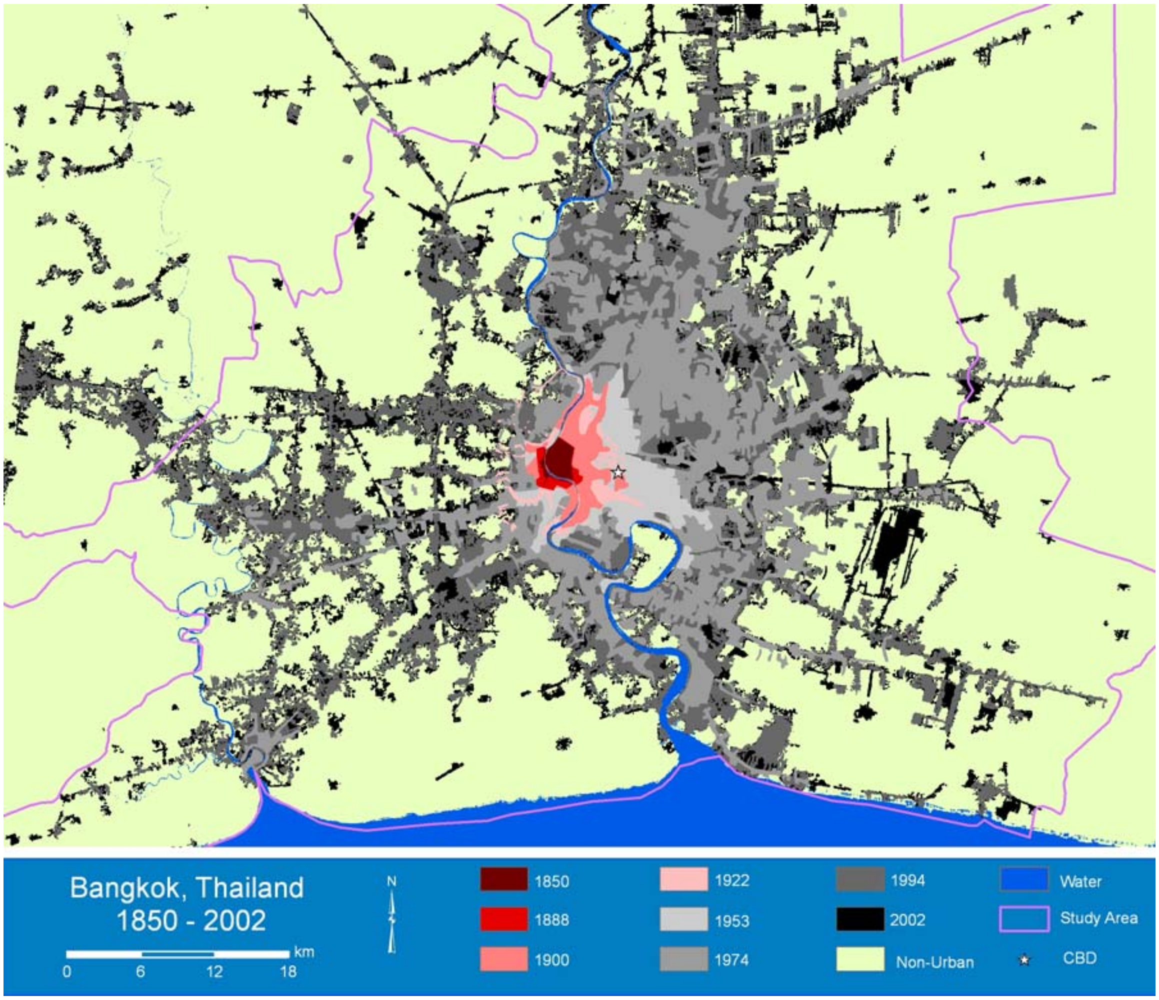

Figure 2: The Expansion of Bangkok, 1850–2002

When we examined the growth rates of urban populations and their associated urban land covers in the global historical sample of 30 cities between 1800 and 2000, we found the rates in Bangkok were not atypical: 28 of the 30 cities studied increased their areas more than 16-fold during the twentieth century. The only exceptions were London and Paris, the two largest cities in the sample in 1900. These two cities had increased their areas 16-fold since 1874 and 1887 respectively.

On average, the 30 cities in the global subsample doubled their urbanized area in 16 years (1930–1946), doubled it again in 15 years (1946–1961), doubled it again in 15 years (1961–1976), and doubled it yet again in 23 years (1976–2000). Their urban land cover grew at an average long-term rate of 3.9 percent per annum.

The advocates of urban containment who continue to insist on limits to the expansion of urban areas must come to terms with these facts. When and how could these cities have been contained? How could we contain a metropolitan area that expands up to 16 times its land area in 70 years?

The rapid growth in global urban land cover is likely to continue as long as urban populations continue to grow, incomes continue to rise, and urban transport remains relatively affordable. While considerable urban expansion may still occur in developed countries, most expansion in the coming decades will take place in the developing world. This note therefore seeks to refocus the attention of planners, policy makers, and concerned activists on urban expansion in developing countries and to examine the policy implications.

Urban Land Cover in Large and Small Cities

We define large cities as those with populations of 100,000 or more circa 2000, and small cities as those with populations of less than 100,000. Large cities are to be distinguished from megacities, those few metropolitan areas across the globe that may contain 10 million people or more. In the year 2000, there were only 16 such metropolitan areas in the world,[2] compared to 3,646 large cities.

These large cities contained some two billion people in the year 2000 and occupied a land area of 340,000 km^2 (table1). Seventy percent of these cities and 70 percent of the total population of large cities were in developing countries, but they occupied less than one-half of the total land cover of all large cities. The shares of the total urban population in large cities in different regions ranged from 52 to 89 percent, with an average of 69±4 percent.

	Large Cities			
Region	Number of Cities	Total Population (millions)	Share of Urban Population (percent)	Total Land Cover (km^2)
Eastern Asia & Pacific	891	458.1	89.2	42,218
Southeast Asia	196	107.3	52.2	12,883
South & Central Asia	539	287.0	65.9	29,705
Western Asia	157	89.6	73.6	12,999
Northern Africa	115	53.1	61.1	5,342
Sub-Saharan Africa	256	131.6	63.4	12,778
Latin America & the Caribbean	403	258.9	66.3	43,280
Europe & Japan	799	400.9	66.5	85,871
Land Rich Developed Countries	293	226.9	84.8	94,759
Developing Countries	2,557	1,385.5	70.7	159,206
Developed Countries	1,092	627.8	72.1	180,630
World	3,649	2,013.3	71.1	339,836

Table 1: Regional Data on the Number, Population, and Built-Up Areas of Large Cities, 2000

In the world at large, large cities accounted for 71 percent of the urban population. We should expect the respective shares of the urban population in small and large cities in all regions to be quite similar, but this is apparently not the case. This quandary is left for further investigation by other researchers.

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2 United Nations Population Division. 2008. *World urbanization prospects: The 2007 revision*. New York: United Nations Department of Economic and Social Affairs. File 11a.

The Mod500 global land cover map used to identify and study large cities could not be relied upon for calculating urban land cover in smaller cities and towns not easily distinguished from villages. To estimate total urban land cover in small cities in each country, we first computed the total urban population in small cities and towns as the difference between the country's total urban population (estimated by the UN) and our calculated total population of large cities, both in the year 2000. Readers must bear in mind that because these estimates come from different data sources subtracting them from one another can be problematic.

In our multiple regression models of urban land cover of large cities, we found that a doubling of the city population was associated with a 16.0 percent increase in density, and we used this density-population factor in generating our estimates. The density metric of interest in estimating urban land cover is overall density, defined as the ratio of the total urban population to total urban land cover in a given area.

Total urban land cover in small cities was then calculated as the ratio of the total population to the overall density in small cities. We estimated the overall density in small cities in every region from information on the overall density in large cities, the median city population in large cities, the median city population in small cities, and the density-population factor introduced earlier. According to our calculations, overall densities in small cities are roughly half those in large cities, and urban land cover in small cities added 266,039 km^2 to total global urban land cover in the year 2000.

Urban Land Cover in All Countries, 2000

We combined our estimates of urban land cover in large and small cities to calculate the total in all countries and world regions in the year 2000.[3] Table 2 summarizes our estimates for total urban land cover in each region, urban land cover in each region as a share of its total land area, and urban land cover as the share of its total arable land area.

Worldwide, urban land cover occupied 0.47 percent of the total land area of countries, ranging from 0.62 percent in all developed countries to only 0.37 percent in developing countries. Urban areas occupied 0.85 percent of the land area of the countries of Southeast Asia, but only 0.12 percent in the countries of Sub-Saharan Africa. Urban land cover amounted to 4 percent of the total arable land area in the world as a whole, ranging from 1.5 percent of the arable land area in Sub-Saharan Africa to more than 5.5 percent in Latin America and the Caribbean and in Europe and Japan.

Among the 20 countries with the largest areas of urban land cover, five of them—United States, China, Brazil, India, and the Russian Federation—had more than 25,000 km^2 of urban land cover in the year 2000 (figure 3). The United States contained 112,220 km^2 of urban land cover, or 18.5 percent of the global total, and more than double the 47,169 km^2 in urban land cover in the next highest country, China.

[3] See Angel, S., J. Parent, D. L. Civco, and A. M. Blei. 2011. *The Atlas of Urban Expansion,* online at www.lincolninst.edu/subcenters/atlas-urban-expansion, table 3.

Region	Total Urban Population (Millions)	Urban Land Cover in Large Cities (km²)	Urban Land Cover in Small cities (km²)	Total Urban Land Cover (km²)	Urban Land Cover as Percent of Total Land Area	Urban Land Cover as Percent of Total Arable Land
Eastern Asia & Pacific	514	42,218	10,760	52,978	0.45	3.39
Southeast Asia	206	12,883	21,565	34,448	0.85	3.64
South & Central Asia	435	29,705	30,166	59,872	0.58	2.30
Western Asia	121	12,999	9,714	22,714	0.49	4.68
Northern Africa	87	5,342	6,775	12,104	0.15	2.69
Sub-Saharan Africa	208	12,778	13,721	26,500	0.12	1.54
Latin America & the Caribbean	390	43,280	47,952	91,233	0.45	5.63
Europe & Japan	602	85,871	88,755	174,581	0.76	5.62
Land Rich Developed Countries	268	94,759	36,688	131,447	0.50	4.63
Developing Countries	1,960	159,206	140,655	299,847	0.37	3.20
Developed Countries	870	180,630	125,444	306,028	0.62	5.14
World	2,830	339,836	266,099	605,875	0.47	3.95

Table 2: Estimated Urban Land Cover in All Regions, 2000

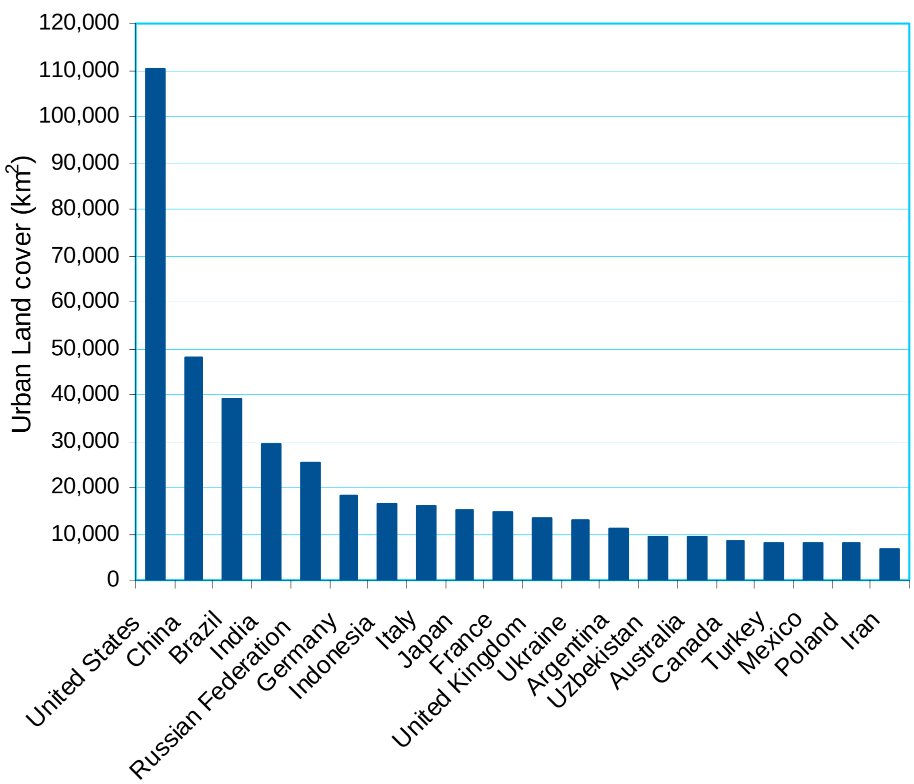

Figure 3: Twenty Countries with the Largest Areas of Urban Land Cover, 2000

Figure 4 shows urban land cover as a share of the total land area of countries that had large cities in 2000.

- 10 countries had more than 5 percent of their total land area occupied by cities, among them Singapore, Bahrain, the United Kingdom, Italy, and Germany.
- 22 countries had 2 to 5 percent, among them Japan, France, and the Philippines.

- 22 additional countries had between 1 and 2 percent, among them the United States, Bangladesh, Turkey, and India.
- 28 more countries had between 0.5 and 1 percent of their total area occupied by cities, among them Indonesia, Pakistan, Venezuela, and China.
- 27 countries had between 0.2 and 0.5 percent, among them Brazil, Mexico, and Egypt.
- 18 additional countries had between 0.1 and 0.2 percent, among them the Russian Federation, Saudi Arabia, and Australia.
- The remaining 28 countries had less than 0.1 percent of their land in urban use, among them Canada, the Democratic Republic of Congo, Libya, and Mongolia.

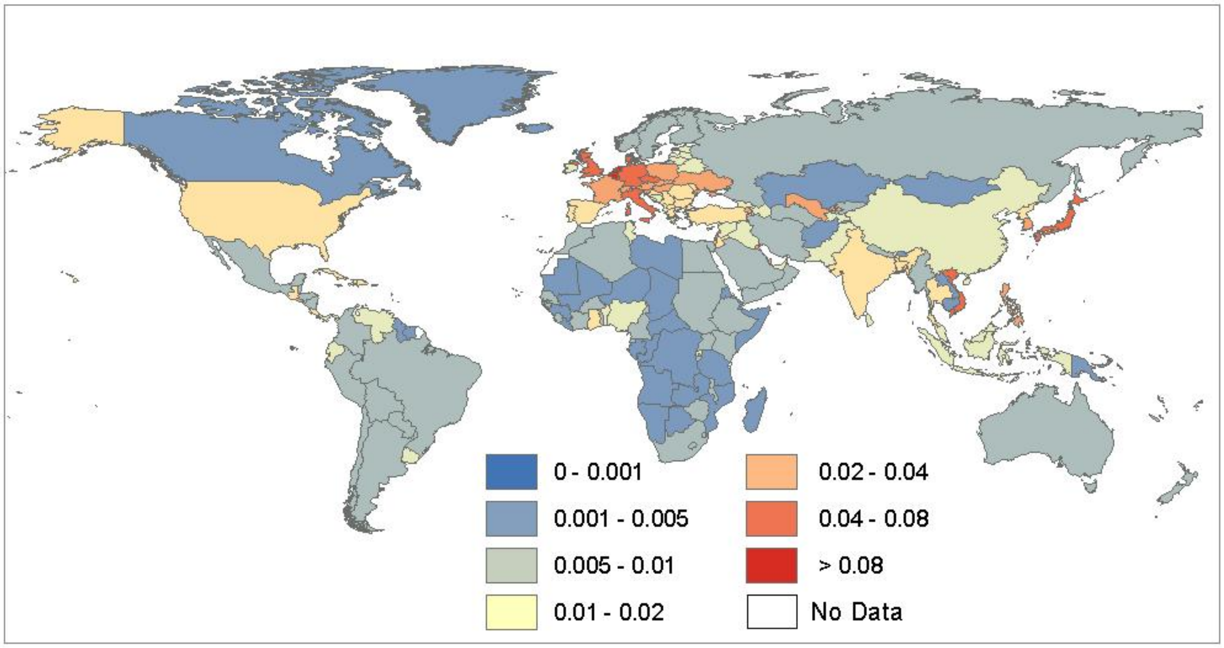

Figure 4: Urban Land Cover as a Share of Total Land Area in All Countries, 2000

Figure 5 shows urban land cover as a share of arable land in all countries that had large cities in 2000.

- 5 countries had more land in urban use than arable land: Singapore, Bahrain, Kuwait, Djibouti, and Qatar.
- 3 countries had more than half the arable land cover in urban use: Puerto Rico, Iceland, and Belgium.
- Urban land in 12 countries comprised 20 to 50 percent of arable land cover, among them the Netherlands, Japan, and the United Kingdom.
- 14 more countries it comprised 10 to 20 percent of arable land cover, among them the Republic of Korea, Venezuela and Germany.
- 29 additional countries it comprised 5 to 10 percent of arable land cover, among them Egypt, the United States and Brazil.
- 45 more countries it comprised 2 to 5 percent of arable land cover, among them Iran, Argentina, China, and the Russian Federation.

- 35 more countries it comprised 1 to 2 percent of arable land cover, among them India and Canada.
- The 12 remaining countries had urban land cover that comprised less than one percent of arable land cover, among them Tanzania and Afghanistan.

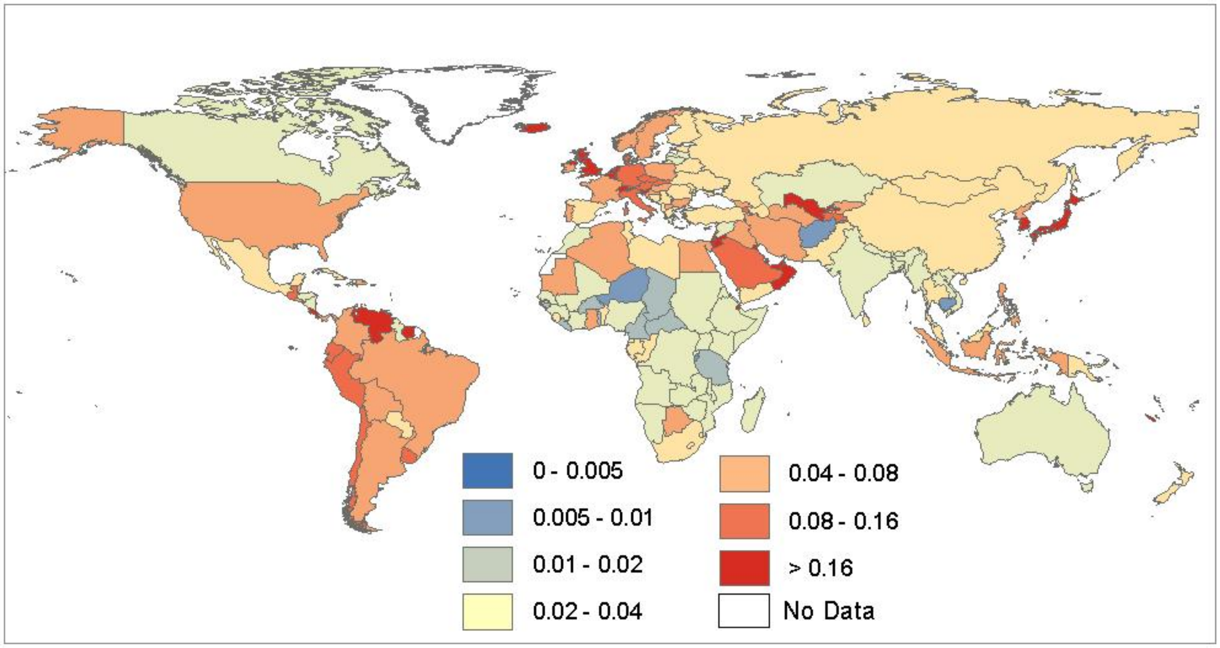

Figure 5: Urban Land Cover as a Share of Arable Land in All Countries, 2000

Explaining the Variations in Urban Land Cover

Multiple regression models were able to explain 93 to 95 percent of the variations in urban land cover among countries.

- A 10 percent increase in the urban population is associated with a 9.3±0.1 percent increase in urban land cover.
- A 10 percent increase in GNP per capita is associated with a 1.8±0.3 percent increase in urban land cover.
- A 10 percent increase in arable land per capita is associated with a 2.0±0.0 percent increase in urban land cover.
- A 10 percent increase in gasoline prices is associated with a 2.5±0.4 percent decrease in urban land cover.
- A 10 percent increase in informal settlements is associated with a 0.08 percent decrease in urban land cover.

In a second set of models, we obtained similar results using the total land area in large cities in the country in the year 2000 as the dependent variable. In a third set of models, we used the urban land cover in individual cities in the year 2000 as the dependent variable. These models were able to explain almost 70 percent of the variations in urban land cover in the universe of 3,646 large cities. City population, GNP per capita, and arable land were found to have similar effects on urban land cover in individual cities as those identified for countries. However, the coefficient for gasoline prices was not significantly different from 0 at the 95 confidence level.

In summary, the statistical models were found to be robust and were able to explain a very large amount of the variation in urban land cover among cities and countries. Variations in climate, cultural traditions, or the policy environment in different countries may matter less than the fundamental forces giving shape to the spatial extent of cities: population, income, low-cost peripheral land, and inexpensive transport.

Projecting Urban Land Cover in All Countries, 2000–2050

We studied density change over time in three data sets: the global sample of 120 cities, 1990-2000; a set of 20 U.S. cities, 1910-2000, and a representative global sample of 30 cities, 1800-2000.[4] Based on these reported results, we project that future urban land cover in cities, countries, and regions the world over will take place under three density change scenarios:

(1) **High projection:** Assumes a 2 percent annual rate of density decline, corresponding to the average rate of decline in the global sample of 120 cities, 1990–2000.

(2) **Medium projection**: Assumes a 1 percent annual rate of density decline, corresponding to the short-term rate of density decline by the end of the twentieth century, as observed in the representative sample of 30 cities.

(3) **Low projection**: Assumes constant densities, or a 0 percent annual rate of density decline, corresponding to the observed rate of urban tract density decline in the 1990s in U.S. cities.

It may be argued that in the future effective policies will be found for increasing urban densities, resulting in reductions of the projected urban land cover. However, no such policies have been identified in any country at the present time. Very few cities in the world have densities that are increasing and, to the best of our knowledge, no city has long-term density increases as a result of conscious policies, including the strict containment regimes of London, Seoul, and Portland. In some countries, such as China and India, the high projection may prove to be more appropriate, while in others, including the United States, the low projection may prove to be more realistic. Low projections may also be associated with increases in gasoline prices, as well as declining gas supplies, the increasing cost of gas production, or its increased taxation. If the multiple regression models we investigated are correct, then the doubling of gasoline prices every decade may be sufficient to keep densities from declining. The search for cost-effective and politically acceptable infrastructure strategies, regulations, and tax regimes that can lead to significant overall densification in low density cities must continue in order to make them more sustainable. At the same time, appropriate strategies for managing urban expansion at sustainable densities in rapidly growing cities in developing countries must be identified and employed effectively. No matter how we choose to act, however, we should remain aware that

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[4] For a summary of results, see Chapter 2 of *Making Room for a Planet of Cities*. A more detailed version of this chapter is now under peer review in *The Quarterly Journal of Economics*, based on a working paper titled "The Persistent Decline in Urban Densities; Global and Historical Evidence of Sprawl", online at http://www.lincolninst.edu/pubs/1834_The-Persistent-Decline-in-Urban-Densities.

conscious and conscientious efforts to make cities denser will require the reversal of a very powerful and sustained global tendency for urban densities to decline.

Projected urban expansion between 2000 and 2050 will be mainly a function of urban population growth and density change, assuming that levels of fragmentation of built-up areas by vacant open space (see Chapter 3 of *Making Room for a Planet of Cities* for a discussion of fragmentation) do not decline substantially during the coming decades. The land cover estimates used in our projections were obtained from our Mod500 global map of large cities which has a 463-meter pixel resolution. These larger pixels contain significant amounts of open space. For the global sample of 120 cities, the built-up area calculated from the Landsat 30-meter pixel imagery was 0.71 the Mod500 urban land cover (R^2 = 0.97), and the city footprint containing the open space captured by built-up areas was 1.16 the Mod500 urban land cover (R^2 = 0.92). The Mod500 estimates are therefore not unrealistic estimates of the land needed to accommodate the projected fragmentation in city footprints.

Table 3 summarizes the main characteristics of the projected growth in urban populations in different world regions, based on the latest UN projection (U.N. Population Division 2008).

	Urban Population ('000)										
Region	2000	Annual Growth Rate (%)	2010	Annual Growth Rate (%)	2020	Annual Growth Rate (%)	2030	Annual Growth Rate (%)	2040	Annual Growth Rate (%)	2050
East Asia & the Pacific	517,808	2.67	676,086	2.05	829,877	1.43	957,030	0.91	1,047,771	0.53	1,105,254
Southeast Asia	206,683	3.27	286,579	2.44	365,769	1.84	439,465	1.42	506,485	1.03	561,580
South & Central Asia	406,151	2.51	522,270	2.72	685,217	2.7	897,250	2.32	1,132,092	1.89	1,368,296
Western Asia	163,087	2.22	203,587	2.03	249,445	1.67	294,920	1.38	338,476	1.08	377,265
Northern Africa	84,167	2.39	106,877	2.27	134,047	2.01	163,815	1.71	194,340	1.35	222,442
Sub-Saharan Africa	210,046	3.7	304,090	3.48	430,685	3.21	593,917	2.85	790,099	2.45	1,009,641
Latin America & the Carib.	393,208	1.79	470,187	1.42	541,737	1.06	602,256	0.75	649,477	0.48	681,383
Europe & Japan	603,134	0.21	615,652	0.17	626,196	0.17	636,618	0.08	641,597	-0.04	638,840
Land-Rich Developed Countries	269,694	1.36	308,949	1.13	346,025	0.91	378,910	0.73	407,479	0.59	432,456
Developing Countries	1,981,149	2.6	2,569,675	2.31	3,236,777	1.99	3,948,653	1.65	4,658,742	1.34	5,325,861
Developed Countries	872,829	0.58	924,601	0.5	972,220	0.44	1,015,528	0.33	1,049,076	0.21	1,071,296
World	2,853,978	2.02	3,494,276	1.86	4,208,997	1.65	4,964,182	1.4	5,707,818	1.14	6,397,158

Table 3: Urban Population Projections for Different World Regions, 2000–2050

- The world urban population is expected to increase from 3 billion in 2000 to 5 billion in 2030 and to 6.4 billion in 2050.
- The rate of increase of the world urban population is expected to slow down from 2 percent per annum in 2000 to 1.65 in 2030 and to 1.14 percent in 2050.
- The urban population in developing countries will grow at a rate five times faster than the urban population in developed countries.
- The urban population of the developed countries will stabilize at around 1 billion people.

- Almost all the growth in the world urban population will take place in developing countries: It will increase from 2 billion in 2000 to 4 billion in 2030 and to 5.5 billion in 2050.
- Among countries in the developing regions, the fastest growth in the urban population will occur in Sub-Saharan Africa, followed by South and Central Asia.

The projected rate of increase in urban land cover will be higher than the rates of increase of the urban population because urban population densities can be expected to decline.

Figure 6 and table 4 show the increases in urban land cover in different world regions under the three density scenarios (for country projections see Angel et al. 2010e, table 4). At constant densities, the world's urban land cover will only double between 2000 and 2050 as the world's urban population doubles. At a 1 percent annual rate of density decline it will triple. At a 2 percent annual rate of decline it will increase more than five-fold. According to our high projection, urban land cover in Sub-Saharan Africa will expand at the fastest rate: more than 12-fold between 2000 and 2050.

If average urban densities in developed countries remain unchanged (low projection), then their urban land cover will grow by only 20 percent between 2000 and 2030 and by 29 percent between 2000 and 2050: from 300,000 km^2 in 2000 to 370,000 km^2 in 2030 and to 400,000 km^2 in 2050. Assuming that densities in the developed countries decline, on average, by only 1 percent per annum (medium projection), urban land cover will grow by 63 percent between 2000 and 2030, and by 113 percent between 2000 and 2050: from 300,000 km^2 in 2000 to 500,000 km^2 in 2030 and to 650,000 km^2 in 2050.

In other words, at a 1 percent annual decline in average densities, urban land cover in developed countries will double in 50 years. If incomes continue to increase relative to gasoline prices and densities continue to decline at the rate of the 1990s, then urban land cover in developed countries will more than double between 2000 and 2030, and will triple between 2000 and 2050.

The situation is likely to be more critical in developing countries, where most urban population growth will take place. Assuming that their densities decline, on average, by only 1 percent per annum (medium projection), urban land cover will grow by 170 percent between 2000 and 2030, and by 326 percent between 2000 and 2050: from 300,000 km^2 in 2000 to 800,000 km^2 in 2030 and to 1,300,000 km^2 in 2050. Assuming that densities in developing countries decline, on average, by 2 percent per annum (high projection), urban land cover will grow by 264 percent between 2000 and 2030, and by 603 percent between 2000 and 2050: from 300,000 km^2 in 2000 to 1,100,000 km^2 in 2030 and to 2,100,000 km^2 in 2050.

The projected urban expansion in all regions, especially the developing countries, in the coming decades should give pause to advocates of global urban containment. It is told that King Canute (1015–1035), annoyed by courtiers who told him he was an all powerful king who could even hold back the tide, had his throne placed on the beach and ordered back the tide, only to get his feet wet. Heroic as it may be, and justified as it may be, containing the oncoming global urban expansion is much the same as holding back the tide.

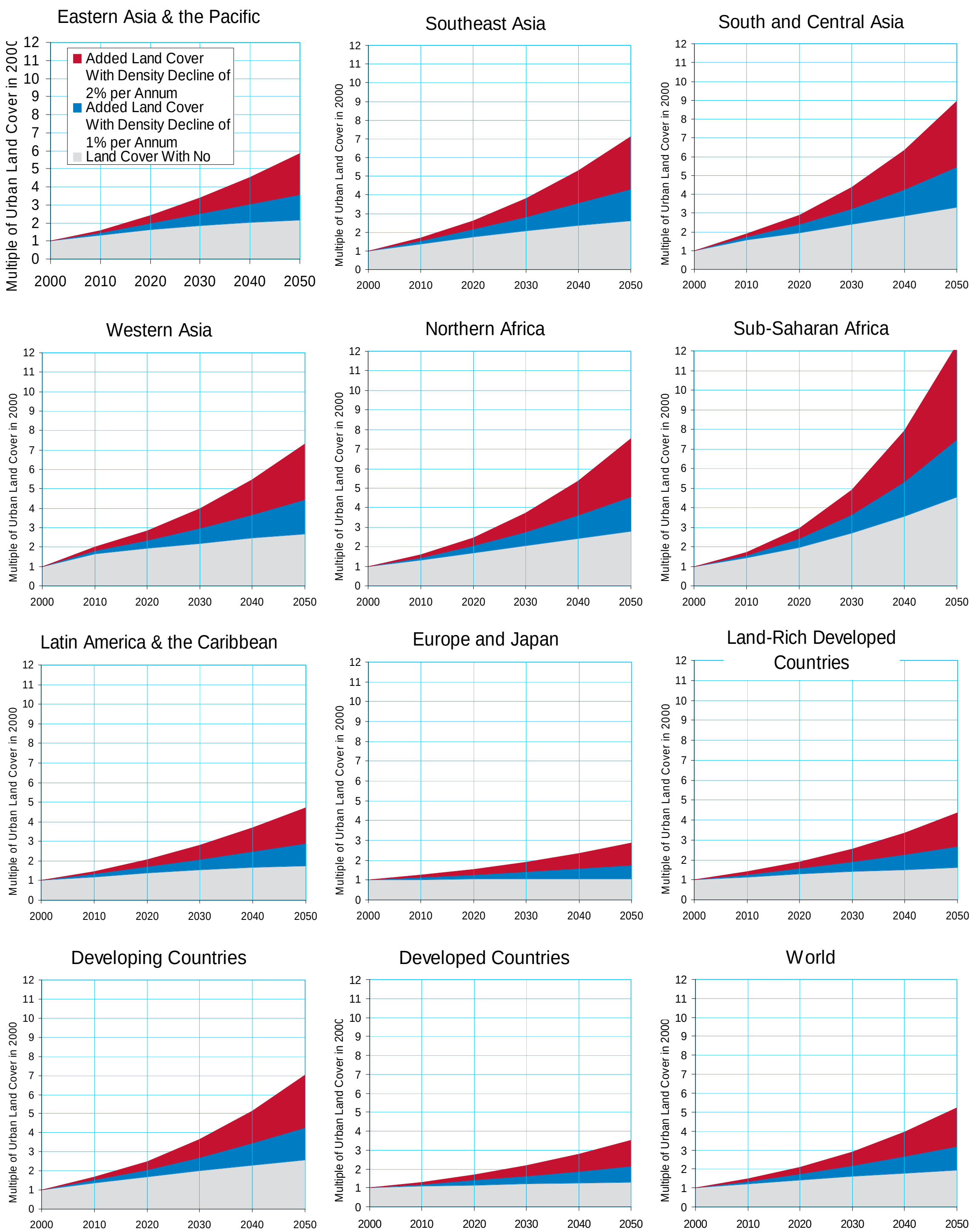

Figure 6: Projections of Urban Land Cover for World Regions, 2000–2050

Region	Urban Land Cover, 2000 (Km²)	Annual Density Decline (%)	Urban Land Cover Projections (km²)				
			2010	2020	2030	2040	2050
East Asia & the Pacific	52,978	0	69,225	85,086	98,329	107,916	114,154
		1	76,505	103,925	132,730	160,991	188,208
		2	84,552	126,934	179,167	240,170	310,302
Southeast Asia	34,448	0	47,520	60,166	71,641	81,848	89,952
		1	52,518	73,487	96,705	122,103	148,306
		2	58,041	89,758	130,538	182,156	244,516
South & Central Asia	59,872	0	93,434	116,653	143,282	171,123	197,324
		1	103,261	142,480	193,410	255,286	325,332
		2	114,121	174,026	261,076	380,842	536,382
Western Asia	22,714	0	37,127	43,418	49,931	55,933	61,041
		1	41,032	53,031	67,400	83,442	100,639
		2	45,347	64,772	90,981	124,480	165,926
Northern Africa	12,104	0	15,782	20,093	24,676	29,277	33,519
		1	17,441	24,542	33,309	43,677	55,263
		2	19,276	29,975	44,962	65,158	91,113
Sub-Saharan Africa	26,500	0	37,568	52,304	71,375	94,325	120,182
		1	41,519	63,884	96,347	140,716	198,147
		2	45,886	78,028	130,054	209,924	326,689
Latin America & the Caribbean	91,300	0	109,552	126,218	140,209	151,227	158,925
		1	121,074	154,164	189,262	225,605	262,023
		2	133,807	188,296	255,477	336,563	432,002
Europe & Japan	174,514	0	177,635	180,569	183,661	185,162	184,439
		1	196,318	220,547	247,917	276,230	304,089
		2	216,964	269,377	334,653	412,086	501,358
Land-Rich Developed Countries	131,447	0	150,691	168,848	184,906	198,850	211,039
		1	166,539	206,232	249,597	296,649	347,944
		2	184,054	251,892	336,920	442,549	573,663
Developing Countries	299,915	0	410,208	503,939	599,442	691,649	775,096
		1	453,350	615,512	809,163	1,031,819	1,277,918
		2	501,029	751,788	1,092,255	1,539,294	2,106,931
Developed Countries	305,961	0	328,326	349,417	368,567	384,012	395,478
		1	362,856	426,779	497,513	572,879	652,033
		2	401,018	521,269	671,573	854,635	1,075,021
World	605,875	0	738,534	853,355	968,009	1,075,661	1,170,575
		1	816,206	1,042,291	1,306,676	1,604,698	1,929,951
		2	902,048	1,273,057	1,763,828	2,393,929	3,181,952

Table 4: Projections of Urban Land Cover for World Regions, 2000–2050

* * *

Creating Synergies from Individual Case Studies: Knowledge Networks, Data Repositories

A significant issue facing the urban remote sensing monitoring and land change modeling community is building synergies from individual efforts on case studies. Notwithstanding the significance of findings particular to each urban area, comparisons are more likely to generate essential insights than stand-alone studies of cities. Therefore, a more concerted effort by scholars needs to be made to crystallize the similarities and differences between disparate urbanization dynamics in different regions and countries.

Urban remote sensing monitoring and land change modeling community can address this issue in several ways. One possibility is organizing the existing knowledge and data that are fragmented across numerous case studies from around the world in a shared online repository. Another would be forming a network of academicians, practitioners, and other stakeholders who would both contribute to the repository and create new collaboration and cooperation opportunities and contribute to identification of research needs and opportunities. Around these two main themes, there are a number of factors that need to be taken into consideration.

Addressing this issue is important because different geographies may call for different mixes of available sustainability strategies in the course of urbanization; the availability of these strategies to decision-makers can help them formulate sustainability strategies specific to their urban areas. On the other hand, in the belief that their circumstances have unique characteristics decision-makers and stakeholders are in general reluctant to learn from others' experiences or sharing their own experiences.

Building a repository that holds the data, results, methodological details from case studies around the world can contribute towards formation of a widely-accessible knowledge network. The repository can be accompanied with an initiative to encourage the research efforts to encompass full spectrum of different city sizes across different regions around the world. To this end, first a template to facilitate consistency across comparisons between monitoring and forecasting in different geographies should be formulated. The template can be used to organize the repository along several dimensions such as –for monitoring, type of sensor, temporal/spatial/spectral resolution, start and end of monitoring period, –for forecasting, the location of the case study (region, country, continent, climatic zone, ecoregion), modeling approach(es), spatial and temporal scales considered, and –for both monitoring and forecasting, the urban population and urban land extent of the case study, the purpose of the study, research questions, and end-users. Many more such features can be included in a final list. The repository organized according to this template can be used, in addition to serving as a measure of consistency, to quantify the distribution of case studies along any of these dimensions.

A network similar to that of The Integrated History and Future of People on Earth (IHOPE) can function as a platform where social and natural sciences interact. Another approach may be integrating urban monitoring and land change modeling scholars to one or more of the existing frameworks such as those of DIVERSITAS programme or the FluxNet. Either way, there will certainly be logistical and programmatical challenges to be dealt with.

A related and promising development regarding the coordination and knowledge sharing issue –among land change scientists– is the GLOBE demonstration project by Erle Ellis of University of Maryland. There are existing procedures in several organizations, e.g., National Institutes of Health (NIH) and World Climate Research Programme (WCRP), that can be taken as examples in formulating policies to that end. For instance, in the NIH model of free and open access to scientific data, after the data is stored in a designated repository by the PIs, there is an embargo period to give the researchers who produced the data the chance to work on it first. When the embargo expires the data becomes open-access. The Urban Climate Change Research Network (UCCRN) is an exemplary approach where scholars and policy-makers from small and large cities from developing and developed countries provide data and information on their cities to each other to aid in urban decision-making (Rosenzweig *et al.* 2010). Scholars and practitioners who work on urban remote sensing monitoring and urban land-use models can either take an active part in the UCCRN or take it as an example to form their own network(s) – which would probably be organically linked to UCCRN.

Building a valid model is an important step but we also need to ensure that valid models are also informative and useful models. This means that they must become integral components in policy-making. This can happen only when the reward structure for academicians is revised so that it takes into account their effort for implementation of their models. Currently, most models remain as academic exercises and inaccessible to a wider audience. This calls for full documentation, streamlining across different modeling approaches, and development of pedagogically-informed model building and analysis tools. In addition, among those that reach the implementation stage, it is important to collect stories of failed implementation of monitoring or modeling studies as well as successful ones. Both can provide a wealth of information on the factors that influence the potential of a study to make a meaningful impact.

Relevant to streamlining a standardized and comparable approach that can encompass urban areas in different natural and cultural settings, we could consider using standard metrics. The concept of *emergy* is such a metric that was proposed as a unifying framework to bring an ecosystem-view of economic activity (Odum 1996). It appears that while such concepts are useful in framing processes in urban areas in different cultural and natural settings we still need to go beyond the common framework to be able to draw useful lessons from each case study. In short, it is probably worth to think afresh how best to utilize available tools and concepts in forming a common platform across case studies.

The differences or similarities among different urban areas are much more apparent in their patterns rather than in amount of urban area. Moreover, urban patterns may matter more than simple attention to rates and magnitudes of urban land change. Thus, perhaps relatively more emphasis on patterns in comparisons of case studies than on the absolute amount of growth (Schneider and Woodcock 2008) is justified.

Other factors to consider in the context of case studies

Participatory approaches: We also need to explore incorporating participatory approaches to model building and testing phases. This is important not only to increase the validity of the model but also to increase the likelihood of buy-in by the stakeholders, which in turn ensures the success at the implementation stage. Devising ways to ensure stakeholders have access to the data, methods, and analysis results is critical as is more active and frequent collaboration between academics and practitioners.

Discrepancy among developed and developing countries: In addition to the discrepancy between developed and developing country cities, there is also an uneven distribution of monitoring and modeling studies within developing country regions. For instance, Middle East has drawn very little attention in monitoring and modeling although it presents very interesting questions regarding urbanization in an arid environment and under threat of civil and military conflict. The logistical issues differ even across developing countries. We need to find novel ways to compensate for the lack of data from these locations. Citizen mapping can be used both in monitoring and validation of land-use forecasts.

A strategy to prioritize case studies: How a city evolves spatially over time is shaped by the type of dominant governance regimes in addition to a larger set of socio-economic factors. Although globalization leads to a convergence in urban forms across the world, the physical, historical, and sociocultural forces still play a role in the process. Paying equal attention to both similarities/commonalities and differences have a great potential to reach a deeper understanding on the forces that shape urban form as well as interactions between different regions of the world. The importance of historical precedent and sociocultural and sociopolitical factors require the inclusion of social scientists (historians, cultural geographers, anthropologists etc.) or at least a consideration of these factors to make a better sense of the results of the monitoring; this is also important in deciding what factors to include in building dynamic models of these urban areas to predict their future patterns. Case studies are essential in this respect to be able to capture these trends in different parts of the world. It is infeasible to conduct in-depth case studies of each and every urban area on the face of the Earth. A strategy to select representative urban areas as case studies may include the criteria that are based on population, governance regime (national and city), economic structuring (agriculture-, manufacturing-, or services-oriented), (income and its distribution within the urban area), regional climate or other biophysical factors. This could be one of the tasks of the network mentioned above.

Periodic assessments of the state of the knowledge from case studies are also an important component of a shared knowledge network. Meta-analyses could be conducted with (semi-)regular intervals to keep track of the combined knowledge and data sources from case studies around the world. Such a meta-analysis of urban remote sensing monitoring studies that primarily targets the Landsat-era (i.e., 1972 onwards) was recently conducted (Seto *et al.* 2011). Similar meta-analyses on urban land-use modeling should also be conducted. While not meta-analyses, similar comparative studies on global urban expansion patterns include the case studies of 120 cities from around the world (Angel *et al.* 2005) and Arizona State University's 100 cities project.

Uncertainty: Any template for comparisons across case studies should also include the treatment of uncertainty. The sources of uncertainty may be numerous and it will be helpful to document and quantify as much as possible all significant sources of uncertainty that may affect the monitoring and forecasts of urban land change.

There are a number of stakeholders at local, regional, and global scales who would find standardized procedures, the existence of a knowledge and data sharing network, and the repository invaluable for their own uses. The first in the list are probably city and metropolitan area governments, national and regional planning offices, and other officials whose responsibilities require a solid understanding of the growth of their urban areas and the drivers behind the growth. The research community would benefit tremendously as there will be many more research and collaboration opportunities around the world not to mention the potential synergies with the policy-makers. Certain NGOs, consulting firms, and even multinational companies may also be interested in the wealth of knowledge the repository will contain. Urban residents are the ultimate stakeholders as they are the ones whose livelihoods both shape and are shaped by urbanization.

In conclusion, what will emerge from such a connected scholar and practitioner network is a more complete understanding of urbanization at the local, regional, and global scales. Moreover, a knowledge network based on case studies can help scholars, decision-makers, and stakeholders to formulate responses to sustainability questions that are appropriate for the particular conditions of their own cities. These questions may include but not limited to examples below:

1. What may be the most suitable set of potential strategies for climate change mitigation and adaptation and urban development?
2. What kind of governance and institutional arrangements work best for urban areas with different characteristics?
3. What are the urban forms for different natural and cultural settings that will lessen the overall environmental impact of an urban area?

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Thematic Background Note for UGEC-NASA Workshop

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> *Data*: The support of applications at different scales is supported by the growth of Spatial Data Infrastructures, geo-portals, and private sector initiatives (*e.g.*, Google Earth, Microsoft Virtual Earth, etc.) has resulted in a massive increase in geographical data availability globally at multiple scales. This growth has not been fully coupled by an increase of knowledge to support spatial decisions. Spatial analytical techniques and geographical analysis and modeling methods are, therefore, required to analyze data and to facilitate the decision process. With cities, conceptualized as a concentration of people, it is most striking to find coherence between land use and socio-demographic as well as socio-economic parameters. The statistical analysis of census data infers information on the human usage of the land, the human exposure to potential hazards in the city, and the configuration of each neighborhood indicating the urban quality of life. For example, combining maps of socio-demographic features with land use maps provides information on gender and age distribution connected with proximity to urban green/open spaces, income and building density, or water consumption and level of provision of infrastructure. In this context URS helps by providing spatial information where linked social and physical indicators explain the interrelations between ecological conditions and socio-spatial development.
>
> In terms of forecasting urban growth, a majority of urban growth models focus on cities in high income countries where data are typically widely available. However, forecasts suggest that in the next two decades most of the urban growth will occur in low-income countries, such as in Asia and Africa. In these cases, data may be nonexistent, incomplete, inaccurate, unreliable, or all the above. One goal is to identify the challenges with developing models in these data-poor contexts? How do we improve on issues regarding data availability and accuracy in these areas? What linkage may exist with remote sensing technology to fill this gap?

This description of the data theme by the workshop organizers raises some critical questions and provides an excellent starting point for this essay. At the risk of being provocative, let me ask another: ***What are the appropriate units of analysis for monitoring, modeling, and forecasting urban growth?*** The phrase "units of analysis" refers here not to the units of specific measurement systems, but rather to the conceptual entities that are subject to measurement and analysis. Tools and techniques commonly used to represent and manipulate geospatial data carry strong assumptions as to what constitute the units of analysis. Geospatial entities include axiomatic geometric objects (*e.g.*, points, lines, polygons, polyhedra) that are located within a spatial reference system. But geospatial entities can also be synthetic geometric objects derived from sensor systems.

An expected response might be, in the context of URS data, the pixel. Let me assert that individual pixels are neither appropriate nor sufficient! This is not a novel position (*cf.* Fisher 1997; Cracknell 1998). Fisher's title conveys the problem: the pixel as a snare and a delusion. Why? Pixels are—almost always—heterogeneous objects. They do indeed convey measurements associated—often loosely—with their nominal geospatial and temporal coordinates. However, it is important not to confuse the packaging of the observations with the things of interest that motivate the observations (Strahler *et al.* 1986), particularly when those things are observed at different scales. A related problem arises with socio-economic data packaged in irregular tessellations: the Modifiable Areal Unit Problem, *cf.* Openshaw (1984), Arbia (1989).

There are no natural *a priori* spatial units. We impose units by our observational processes. Thus, delineations between patches are arbitrary and may be imprecise in location, transitory in duration, and irrelevant to underlying processes of interest. Further, there is no *a priori* ordering of the directionality of causation in space comparable to the "arrow of time." While topological relationships indicate who is neighbor of whom, more information is required to know who the effective neighbors are. This requires the user to inform the geospatial database about the flows of influence among spatially ordered data. Different processes can have different effective neighborhoods at different scales.

Further, in urban remote sensing the images or pictures are themselves *not* the endpoint for scientific analysis; rather, what is of scientific interest is the dynamic of pattern and process that the pictures portray. Consider the analogy of sparse sampling of individual frames or even frame sequences from a movie. One level of analysis could aim at reconstructing motion from these data, but a more sophisticated analysis could aim at *reconstructing the plot*. If we are to delve into the image archives with the aim of advancing our understanding of cities and their regional penumbrae, then we need to advance a program of reconstructing plots, comparing plots, characterizing typical plots, and identifying unusual plots, as well as interesting deviations from typical plots.

Some plots relevant to urbanization and global environmental change include (i) growth and decay patterns of human settlements in various kinds of resource environments and (ii) responses of urbanized areas to disturbances—both anthropogenic and natural—on a variety of timescales, among many others. We can observe aspects of these phenomena from orbital platforms by sensing *reflected solar* radiation (visible to middle infrared), *emitted terrestrial* radiation (middle infrared through thermal infrared and microwaves), and *backscattered anthropogenic* radiation (RaDAR, LiDAR).

The process of observation in remote sensing is a more subtle issue than first it may appear. There is the general problem of observability in a strictly technical sense: Is it possible to sample adequately the phenomenon of interest? Given the loosely coupled and contingent nature of ecological (and even socio-economic) relationships, this question must be addressed at multiple scales (Allen and Hoekstra 1992). But multi-scale sensing has rarely been practiced, though it has often been demonstrated.

In considering the future of spatial analysis and GIS, Openshaw (1994) argued for a "concepts-rich approach to spatial analysis, theory generation, and scientific discovery in GIS using massively parallel computing." He diagnosed a source of malaise that continues to affect the spatial analysis community and then pointed to a possible remedy:

> Pattern searching is not the same as hypothesis testing because there is no relevant null hypothesis. This point was lost on the original quantitative geographers [during the 1970's]. ... [They] failed to develop a statistical theory of spatial analysis as distinct from providing examples of statistical methods being applied to spatial data in search for largely aspatial patterns. **The danger now is that the same mistake will be repeated 20 years later in the GIS era by a failure to appreciate that spatial patterns are themselves geographic objects that can be recognized and extracted from spatial databases.** [Emphases added.]

A key notion here is that spatial and, by extension, spatio-temporal patterns are *observable entities* and *appropriate units of analysis*. Here is a lever by which to build a theoretical framework for spatio-temporal analysis of image time series. To date, theory development for spatial-temporal analysis has been hampered by lack of a suitable framework for identification and quantification of spatio-temporal patterns. Numerous metrics have been proposed for quantifying spatial properties of image data; however, scant attention has been paid to the effective use of these metrics for capturing or summarizing spatio-temporal dynamics, whether in urbanized areas, croplands, grazinglands, or wildlands.

Openshaw's critique also points to the problem of baseline models: "...because there is no relevant null hypothesis." The testing of null hypotheses is one particular form of using neutral models to compare and contrast phenomena. Neutral models are touchstones. They serve a crucial role in scientific investigation by providing archetypes of expectation that guide the development of theory, the design of experiments, and the collection, analysis, and interpretation of data. The most powerful inferential tools in traditional probability theory rely upon the concept of zero-dimensional randomness and its formal model, the Gaussian probability distribution function. Similarly, one-dimensional randomness and its formal model, white noise, provide the touchstone for time series analysis. Various spatially random patterns and processes, such as doubly stochastic Poisson processes, self-avoiding random walks, percolation theory, and conditional and simultaneous spatial autoregressive models provide neutral models for two-dimensional data. With the discovery of fractal geometry and the emergence of complexity theory, new neutral models have become useful to characterize distributed-disordered systems: fractional Brownian motion, Ising and Potts models, Levy flights, self-organized criticality, *etc*.

Notice, however, in this litany of neutral models that abiotic randomness motivates each. This pattern points to a fundamental problem in the use of such neutral models for investigation of biospheric dynamics: the biotic world is not random but—as our ecological understanding demonstrates—it is knowable, albeit *truly* complex. Many sciences must indirectly observe the responses of "their" dynamical systems to various stimuli, either intentional or coincidental. The problem of inferring process from pattern arises from many-to-one mappings in the absence of domain-specific models to *inform* that inference.

So, where can we find domain-specific models to guide informed inference from the rising flood of digital data? We need to build them. Perhaps we need to reinvigorate the concept of cities as nodal regions and work to make this concept interoperate with "traditional" land cover land use change studies. Consider of the manifold dimensions of nodal regions in terms of mass flow of water/carbon/nitrogen, in addition to concentrations of people/information/wealth. We need to explore the resource flow linkages between various subregions of cities and conurbations as well as between smaller cities and their hosting ecoregions to enable forecasting growth velocity, direction, intensification. We need, in particular, to rescale storylines of possible global futures (*e.g.*, SRES, MEA) into *regionally relevant and plausible* alternative scenarios that articulate drivers and constraints on the local level.

That we lack much data in many places is clear. Remote sensing cannot fill those voids, but it can help to constrain the possible. And it may provide us with as-yet-discovered spatio-temporal signatures that are characteristic of dynamics in urbanized environments. These signatures may then provide the units of analysis for investigating the dynamics of the built environment.

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Brief note on 'Scale' for the UGEC Land use forecasting workshop

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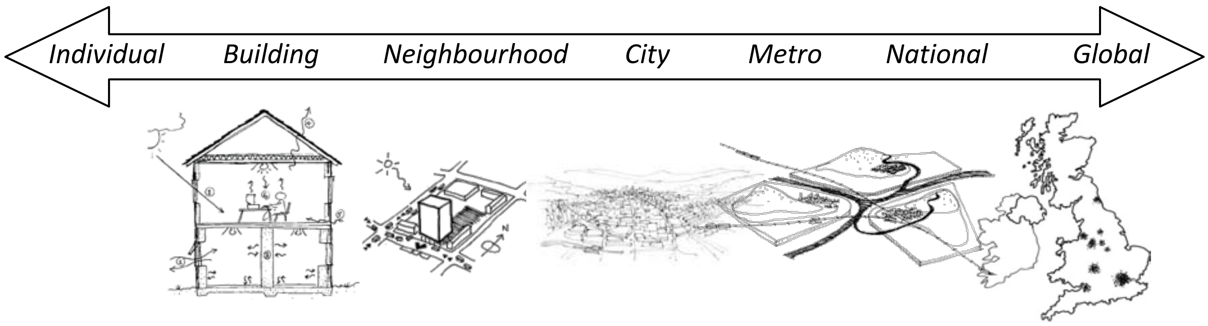
Land use is determined by the interaction in space and time of biophysical factors such as soils, climate, topography, *etc*., and human factors like population, technology, economic conditions, *etc*. These processes play out over a wide range of spatial and temporal scales.



For example, in the context of the urban heat, at different scales different components of the urban system become important: building materials have different thermal properties and subsequent implications for the heat island and roofs can influence airflow locally while the configuration of buildings and infrastructure within the wider urban area has implications for other impacts, such as wind and heat fluxes, flood risk and (waste) water management. Likewise, an individual's wealth and attitudes may shape their transport preferences, but they are also heavily mediated by existing landuse (*e.g.* service and employment locations) and the transport network(s) across the whole city or region.

A multitude of organizations collect vast amounts of data at varying frequencies and resolutions for a diverse set of economic, social, physical and environmental attributes of urban systems. Typically, 'indicators' provide the lowest resolution data. It is clear from the World Bank's Global Cities Indicator Facility (GCIF) and other initiatives that indicators do have a useful role in high level appraisal of priorities but must be interpreted with care and not relied upon exclusively for addressing more detailed policy and planning decisions. However, more detailed data from real time monitoring [1], community developed maps [2] and satellite observations [3] and models [4] is becoming increasingly available. Many cities will have long time records from censuses and weather stations, but more recently mobile phones[5] and social networking datastreams[6] may offer the 'bottom up' capacity to understand the urban 'pulse'. The potential for using this data in all parts of the world is growing as these technologies are rapidly taken up, meanwhile community initiatives for mapping[7], open source web-based platforms [8] and mapping organisations [9] should facilitate modelling studies to be more readily implemented in cities of all continents. From a 'top-down' perspective, remote sensing technologies such as airborne LiDAR and multi-spectral satellite images provide consistent views of a city's physical and biological form and composition[10,11].

In parallel to data at different scales are a range of modelling and simulation methods that operate at different scales, ranging from indicator-based analysis to full on simulation of urban dynamics[12,13]. Clearly, the amount of resource, in terms of data acquisition and analysis that is committed to informing sustainability policy should reflect the nature of the policy decision(s) being analysed. Planning policy frameworks tend to cascade from supra-national (*e.g.* European Union (and possibly global)) and National policy instruments that provide the framework and common understanding through spatial planning in cities to local design and operational decisions. Multiple scales of policy-making require a hierarchy of methods, data and detail of analysis appropriate to each level, examples of which are proposed in Table 1. Through fusing datasets from a diverse range of sources and exploiting their full potential by modelling and analysis, cities will maximise the evidence available to them to ensure more informed decision-making. Although a full range of data will not necessarily be available everywhere, as community initiatives and remote sensing data become more widely accessible, the higher levels of analysis should become feasible in the majority of locations. It is also crucial to note that even in cities with more sophisticated and established governance frameworks, many of the processes and drivers of land use change are informal. These informal processes can be even more significant in developing world nations.

Table 1 Hierarchy of methods, decisions they might be used to inform and the type of data and methods appropriate to the scale of analysis. Many data and models cross scales, it would be misleading to categorise.

	Decisions to inform	**Data and methods sources**	**Methods**	
↑ Increasing scales of analysis	*Benchmarking* Nationwide assessment of sustainability in cities Identification of national priorities Planning policy and national directives *Regional and urban planning* Spatial development strategies Strategic assessments *Detailed design* Neighbourhood planning Infrastructure design Building design and orientation	Satellite observations Energy generation Rainfall, temperature monitoring Traffic and local air quality monitoring Airborne lidar and photogrammetry Property location and land use Population and demographic information Travel, energy, consumption and waste surveys Smart sensors and building air quality, energy and water monitoring Terrestrial and mobile laser scan Individual and mobile phone sensors	Indicator and checklists GIS overlays Global and regional climate model outputs Accounting tools Quantified modelling of risks and sustainability Integrated assessment models Urban metabolism Landuse and demand modelling Weather generators High resolution simulation and process models of selected urban functions Industrial ecology and life cycle analysis Engagement with individuals and community groups	Increasing resolution of monitoring and modelling ↓

At each scale there are a range of relevant drivers, policy/decision-making agents; biophysical and human processes and opportunities for data acquisition. To be meaningful, drivers, decisions and processes need to be described, understood, and modelled at the correct scales. However, of particular importance is understanding the interactions across scales and between different processes which often suffers due to lack of data, or a sector led data acquisition strategies that fails to capture phenomena at sufficient resolution or their broader interactions.

Whilst land use modellers have recognised and are becoming increasingly talented at extracting value from existing data the emerging bottom up datasets still need to be better understood whilst the top-down datasets provide only limited value due to their non-urban focus. For example, AVHRR data has a high revisit time, resulting in up to a maximum of 4 scenes per day being acquired[14] yet some recent work we did in London[15] suggests that even this frequency is insufficient to understand the urban heat island. Sparse ground measurements and cloudy scenes compound this issue.

Ecological research in the USA has benefited from structured, place-based research programmes[16] such as that in Phoenix, Arizona. A similar *Long Term Urban Research* programme to address the challenge of sustainable cities would provide similar opportunities to improve our understanding of cities. This could build on a foundation of data that is already collected at a range of scales by the many stakeholders operating in cities. In many cities worldwide a first step will be to co-ordinate and structure the acquisition and archiving of data and to integrate modelling and analysis activities, before identifying gaps and where necessary commissioning new activity. Data could then be fed into a suite of urban models that can be used for emergency management or long term policy analysis, either for the city in its entirety or for different urban functions. To realise their full potential, these analyses must be visualised and communicated in many ways to satisfy the requirements of different stakeholders who will increasingly need to, and with appropriate tools be able to, interact collaboratively to address the challenges of land use management under conditions of global environmental change.

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Scale and Urban Growth Models
UGEC and NASA Joint Workshop on Urban Remote Sensing (URS) and Forecasting Urban Growth (FORE), April 1 – 3, 2011

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Analysis of urban systems and urban change must be sensitive to the issue of scale, considering how choices made regarding both spatial and temporal *extent* and *resolution* influence the analyses we conduct and the conclusions we draw (Walsh and Crews-Meyer 2002; Verburg, Schot et al. 2004). Urban systems exhibit any number of hierarchies, or levels at which key processes interact and evolve at similar speeds and over similar spatial extents (Simon 1974). Information may be transferred to levels up or down, but stable, recognizable structures emerge (Holling 2001). These recognizable structures, or scale effects, may constitute evidence of these hierarchical processes at work, but in applied research, we encounter the impacts of scale empirically. We may have to conduct extensive inductive analysis to understand scale-specific patterns in our data, which may make it harder to theorize a priori important scales of influence (Munroe and Müller 2007; Manson 2008).

Thus, identifying and accounting for spatial processes at varying scales is challenging. Scale effects can be intrinsic to the data we use: the remote sensing pixel is an artifact of the device, and not related to either social or environmental processes in a straightforward way (Fisher 1997). More generally, there is not necessarily an obvious way to group data by relevant scales; depending on how the data are measured or aggregated, results can vary (Turner, O'Neill et al. 1989; Cressie 1996).

In the sections below, I explore several critical scale issues we often encounter in data-driven modeling of urban growth. A common theme to all these points is the distinction between pattern and process (Nagendra, Munroe et al. 2004), understanding that we generally know much more empirically about the former than the latter. These models are likely to be spatially and temporally explicit, and thus must accurately represent processes that vary over space and time. Urban growth models may be informed by microeconomic principles: that land values shape (but not necessarily dictate) likely trends and transitions in urban form. Here, I focus my comments primarily on conceptualizing and identifying domains of scale. Ultimately, computational modeling that integrates spatially and temporally dynamic feedbacks is necessary to understand the behavior of urban systems (Irwin, Jayaprakash et al. 2009).

Spatial scale

Urban growth models may have to contend with a variety of scale-dependent processes shaping urban form. We must then consider how key processes underlying urban land-use change express themselves over space. At the most basic level, models of urban land-use change increasingly focus on individual decision-making, attempting to understand how individuals choose to live or work in particular locations of the city given locational attributes and variations in land value.

However, individual decision-making in urban areas is strongly mediated by many processes operating at larger spatial extents. Neighborhood effects are often extremely important; many sorting processes happen at this level (Bayer and Timmins 2007). In the United States, local funding of schools often means that perceived variations in school quality can be a substantial determinant of land value. Other political factors can vary at the neighborhood level, including zoning ordinances, taxes, the distribution of service centers (e.g., commercial sites of opportunities) and natural amenities (Carrion-Flores and Irwin 2004; Walsh 2007; Bayer, Keohane et al. 2009; Klaiber and Phaneuf 2010). Neighborhood-level effects are often endogenous: past land-use changes shape current and future neighborhood possibilities. For example, a declining neighborhood may lose tax revenue and not be able to invest in the maintenance of its amenity base (Anacker 2010). Beyond the neighborhood, local land markets can be tied to larger regional or national trends in the macroeconomic economy, and job and housing markets can be endogenously linked (Partridge and Rickman 2003).

There are several techniques that can be used to capture spatial scale effects. Geostatistical techniques, such as variogram analysis, can be used to identify domains of scale within a particular urban setting (Fleming 1999). In a regression context, locally weighted regression (such as GWR) is often used to explore spatial variation in a continuous variable (e.g., parcel sales price) to identify patterns or derive spatially demarcated discontinuities in the relationship between two or more variables over space. This technique is descriptive, and as such, can be useful for investigating the spatial implications of hypotheses drawn from theory (Griffith 2008). Another promising technique is the use of multi-level statistical models, which allow us to identify trends in one variable conditional on processes operating at different spatial extents (Polsky and Easterling 2001). Finally, Bayesian hierarchical models facilitate a process-based description of spatial-temporal change, along with associated uncertainty estimates (Wikle 2003) that can be very useful in understanding the dynamics of an urban system.

Temporal scale

Time scale effects, or patterns in the sequencing of events, can in some cases be more complicated than spatial scale because time can be linear, periodic, cyclic or infrequent (e.g., large-scale shocks). In modeling urban systems, temporal scales generally matter in two related ways. First, we must consider the variable speed at which processes occur (and change), such as labor markets, land markets, land-use policy, and regional and international migration. Secondly (and indirectly following from the first), we must often consider legacy effects, path-dependency, or long-established structures that influence all subsequent urban changes (Pickett, Cadenasso et al. 2005). Perhaps the classic example in an urban area is that of water: there are almost always upstream and downstream effects in sewage and industrial waste that shape subsequent patterns of industrial, residential and commercial activity (Munroe 2007).

A principal challenging in modeling an urban system is the endogeneity of many of its components (zoning, roads, utilities and other local public goods). The relationship between roads and development is particularly polemical. Infrastructure construction and improvements and subsequent land development can co-evolve in highly complicated patterns. From a policy side, this pattern has been debated to argue either that roads cause or roads follow development. Public investments that indirectly subsidize new construction, such as road building or improvements, may lead to more and more fragmented growth (Pendall 1999). Roads also follow development: decisions about subsequent road construction might be made following land conversion and resulting congestion (Baum-Snow 2007). Because such temporal interdependencies can feed back across space and time, models must be able to represent such feedbacks or inferences may be biased.

A third aspect of temporal scale in studying urban growth is making a case for structural change in a given process over time. Irwin and Bockstael (2007) discuss data and methods needed to determine whether urban fragmentation is increasing over space (distance from metropolitan center) and time (1973 vs. 2000); significant differences in land fragmentation patterns could indicate a qualitative shift in urban form associated with exurbanization, or low-density, fragmented urban-dependent development in formerly rural areas. Aspinall (2004) also explores temporal variations in the drivers of land-use change. Using multi-model inference techniques, he shows that over a multi-decadal time period, various factors such as infrastructure become more or less important in explaining overall land-use change over time.

Data availability is critical here. The retrieval of satellite imagery is often dictated by weather patterns or the orbits of satellites (Lambin 1997). Secondary data may only be collected through a decadal census. In fact, urban analysts are often much more constrained in the amount and access to information over temporal domains rather than spatial. Current major efforts include ways to derive datasets longer in duration and richer in sampling frequency. More process-based modeling of urban systems requires much richer data on underlying processes (e.g., individuals, neighborhood groups, political decisions, etc.) and not just the statistical association of these effects at an aggregated level (Brady and Irwin 2011).

Teleconnections

One issue relating to scale that has received substantially less conceptual and analytical attention is that of teleconnections: functional relationships between often distal locations. Accounting for these teleconnections may fundamentally challenge the ways we currently draw boundaries around processes we measure (i.e., a given scale as a "container" of process). Urban systems are clearly not closed; there are critical processes flowing in and out of cities, often daily or even hourly. However, it is conceptually challenging to think about which processes are most critical to represent in an urban growth model. Particularly when we use satellite data to observe changes in urban pattern, we are focused on the snapshot in space and time. How do we begin to integrate processes happening outside of this region, outside of this time point? For example, urban analysts might be able to measure accurately how many people are moving in and out of a city region (depending on how data are collected), but understanding the various "push and pull factors" relative to other locations may be considerably difficult. Without a precise understanding of these factors and their local effects, however, models of urban process may yield biased and misleading results.

The standard approach in the human dimensions community until now has to been to conceptualize ever-larger, more or less nested, more or less hierarchical sets of spatial and temporal extents (and processes acting on those extents) (Holling 2001). For example, see Gibson et al.'s (2000) nested hierarchy of institutional decision-making. While this framework is insightful and sheds critical insights on how decisions are influenced and structured by any number of processes operating above or below, there are shortcomings of this framework that we may seek to improve upon.

Most importantly, "global" decision-making (i.e., processes that cross two more international borders) does not always happen at a global level. One category of actors shaping land use locally by operating globally would be transnational corporations (TNCs) (Jepson 2006; Geist, Otanez et al. 2008). TNCs often operate through complicated networks of places, but ultimately, have a distinct geography. The involvement of distal actors in processes of urbanization can reflect former colonial ties, investment and banking infrastructure, and particular cultural or ethnic diasporas (Seto and Kaufmann 2003). Therefore, their imprint is certainly not global (in the meaning of *universal*). Cities, in turn, depend on web-like connections to many distal places for everyday flows of people, materials and energy (Decker, Elliott et al. 2000). Depending on the research question, greater elucidation of these linkages may be necessary for a richer understanding of how urban systems function and change.

The difficulty in understanding the role of international non-state actors like firms may be hampered by the land-change science community's conceptual adherence to hierarchies (cf. (Perz and Almeyda 2009)). In order to move beyond this impasse, urban modelers may want to think about networks that connect various forms of decision-making at various places on the globe and across various levels of institutional arrangements. To do so might make us reconsider processes that work across multiple scales. Reconceptualizing urban systems as complex adaptive networks to understand interconnections among decision-makers in multiple locations (in space and time) may be a fruitful endeavor toward this end.

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RECAPPING WHAT WE KNOW & IDENTIFING STEPS FOR THE FUTURE

APPLICATIONS

- The challenges and opportunities faced by developed countries vs. developing country cities are different. These differences require different modeling approaches.
- Even with elegant and valid models there remains significant policy-resistance against operationalization of the insights from these models due to political pressures, path dependencies, and other causes.
- Are models comprehensible, accessible, policy-relevant (+ valid)?
- There are competing foci on making models ever more complicated and making models accessible to decision-makers.
- Are we even modeling the right processes? Are there example cities? Cities can learn from each other but particularities of each one of them have to be recognized.
- Ensuring model relevance at local scales is an issue. Can we come up with a typology based on different approaches to land change modeling?
- There are differences of opinions on what is important among the social scientists (economists, geographers, sociologists) – What are the characteristics in common?

Needs for Future Research & Practice

- Improve translations of URS products and applications for better planning and management of cities. Recognize the gap of education from RS researchers to stakeholders.
- Improve capacity building for local regional and national government bodies.
- Simplify the way RS info is communicated to stakeholders, i.e., overviews; narrow the number of metrics related to urban expansion (simplify).
- By employing different modeling approaches in different contexts models could better capture the important details that elucidate urban dynamics and assist decisionmakers.
- There may be learning opportunities from experiences of different cities, but that should be informed by particular conditions of a target city.
- Land ownership issues and property rights have to be recognized in infrastructure planning.
- Include aspects of climate change and ecosystem services in the models.
- We need to scrutinize the actual application of the models. Are they policy- relevant? Are they making a meaningful impact even if they are elegant and valid models?
- It seems that to make an impact, a model has to have a ‘legal weight’ to it and should be cognizant of the nuances among prediction, forecasting, and projection.
- There is value in participatory approaches to modeling and having codes of models open-source.
- Quantify resource sink strengths looking at waste streams to identify material flows associated with different city types.
- Link hazards databases with databases on urban areas, cross-tabulating by various urban forms, types, locations, etc.

CASE STUDIES

- Most studies are on methodologies in the urban RS conferences. Not many policy makers.
- How can case studies be uploaded to J- urban? National level could be more interested in case studies.
- How will an overarching framework be defined and funded?

Needs for Future Research & Practice

- Each is doing their own thing – we need more case studies studying the same things; there are lots of case studies that are not replicated.
- Dynamic ontology to synthesize case studies.
- Meta-analysis – i.e., putting out a new call to authors to submit information on their recent publications.
- Asking researchers to drive case studies from particular scenarios of GEC, to get a richer picture of links between environmental change and urbanization.
- Frameworks:
    - Framework for case studies – how to make sense and synthesize;
    - Framework to translate generically, case studies to policymakers. Adapting models developed from one city to another requires a framework that includes interactions between policymakers and scientists;
    - There doesn't need to be one framework that every case study fits in, but should draw out the richness of the case studies that have been done;
    - Depth vs. breadth – need detailed experiments with a unifying theory. 100 Cities Project intends to collect a uniform data set over 100 cities. Will compare case studies using the above-mentioned framework. Create a framework that everyone will work by to create a momentum.
- Voice to NASA that there is a critical mass and consistent set of criteria to fit a variety of models and methodologies. How do cities fit to the overall process and bigger picture of NASA? What is the missing link?
- India – the urbanization rate is fast! Need to consider medium size and small cities.
- Establish a scientific body to discuss and define the criteria. Problem with 100 Cities is that some cities were considered unimportant when other issues emerged such as a volcano/flood. How broadly in the government are the priorities determined?
- Communicate the important of cities. Continue case studies with a common framework. Who will do the case studies? They don't advance theory and methodology, hence rejected from publications…the case study needs to be based on a hypothesis that a city behaves a certain way.
- Need to consider how the specific city society will benefit from that case study.

DATA

- There a lot of studies on methods, but few on policy.
- What is the product that we should be developing? How do we frame data so that people understand it and use it?

- Global Earthquake Model (www.globalquakemodel.org) project is building a global database, may build on that for adding socio-economic variables;
- Available population data from RS is at a too coarse resolution to be useful for urban planners.
- Non-RS people are skeptical about what RS can provide.
- Technology and networks are creating new opportunities, data and methods of collection.
- Global Energy Assessment dataset and the Global City Indicators facility - They could be integrated into J-urban.
- Some data is limited in all places, in some places all data is limited, (i.e., due to issues of privacy or security, governments are not willing to release full datasets out of fear of identifying individuals or providing potential terrorists with information).
- There are no "decision boundaries". Across the world it is not guaranteed that administrative boundaries actually exist, in some places they do, but change quite frequently and databases are not maintained.
- In some developing world contexts, there are data which simply are not collected or lack the same credibility or validity as similar data collected in developed world cities.
- How to make data useful? How to reach out and show that is useful?
- Model outputs devoid of context are not necessarily useful to the decisionmaking community; discussions of data should not be focused on model inputs alone, but model outputs, as well.
- URS-related Distributed Active Archive Centers (DAAC) data are unknown to non-science users.

Needs for Future Research & Practice

- Emphasis should be placed on data products.
- Web site with links to repositories would be useful.
- Need for a user-friendly interface to the data if Earth data is to be addressed.
- It would be useful to let people upload data to collections of field-based data, J-urban / J-earth: A Google Earth-like initiative on what is already there (J for Java), i.e., Integrating framework to compile and make available lots of data.
- Need to integrate ancillary data in order to generate new "data product", the RS-only data product are basically exhausted.
- Accommodate socio-economic variables.
- Need for integrating satellite data and local variables.
- Need tools to convert data into a format compatible with the environment with which people are familiar.
- Approaches are needed to translate model results for policy makers.
- Stakeholders should be involved with model development.
- Taking advantage of merging a wide-range of top-down and bottom up data sources can improve modeling and analysis.
- Exchanging data should be a priority.
- A wide array of bottom-up and top-down sources of data exist, even in supposed data-poor areas; however, these data have not typically been combined. Merging these disparate sources of data — often archival data that has not been geocoded or validated,

as well as qualitative data cleaned from interviews and surveys — with other sources of top-down data, such as that which can be remotely sensed, can improve analysis and modeling efforts and, in turn, provide new insights into processes occurring in urban areas.

- Explore reconceptualizing the city to extend beyond physical spatial boundaries to loci in multiple networks (actual and virtual) representing flows of people, material, money, and information.
- Aggregating/linking formal and informal data (e.g., narratives, news stories, digitized/digitizable journal articles and monographs) through automated geotagging & keyword extraction enabled by application of natural language processing (NLP) technologies [NGA was looking to fund this kind of research about 5-10 years ago].
- Need to develop ontologies to inform semantic web about 'urban'. First develop taxonomies around urban form, structure, pattern, growth, and associated phenomena (e.g., UHI, densification, impervious surface) using expert groups.
- Refine into ontologies using CS folks knowledgeable about the process.
- Implement and promote via website, community buzz, articles, presentations, etc., seek global storylines from new efforts to update SRES (e.g., Moss et al. 2010, Nature 463, 747-756) but develop regional storylines by thinking through regional constraints/opportunities.
- Need common algorithm to search all DAACs.
- Improve data comparability and compatibility.

SCALE

- URS/FORE have completely different concepts of scale; FORE: abstract; URS: strict (depending on phenomena).
- Difficult to come up with common definition of city.
- Common question: Does scale dictate application?
- The fact is we must live with scale.
- How do cities scale?
- Do temporal patterns of cities exhibit scaling properties?
- How do cities diverge from scaling?
- Can scaling relationships enable classification of cities in a data-poor context?

Needs for Future Research & Practice

- It is necessary to define what scale is and consider the various levels at which it can be conceived and to make clear the limitations of working at that scale.
- Different phenomena should be seen at different scales (optimally "sweet spot" scales at which one does not loose modeling capacity due to random factors) such as:
    - Extent (areal), e.g., an ecological footprint of expansion of a Chinese city. We can do case studies at city level and link this to the global - urban metabolism or efficiency;
    - Grain size (pixel) with respect to different times;
    - Temporal range;

    - Levels of governance – household, community, city, state, national, regional, global, etc.;
    - Categories.
- To be able to understand scale it should be conceived in terms of its relationship with processes and the data needs/requirements.
- Important to employ a framework (ontology or protocol) that will lead us in our selection of scale(s) in the analysis of urban phenomena.
- Should work across scales, and choose the scale or scales most appropriate to the phenomena under consideration.
- In developing a framework, this could be based on stakeholders – knowing scale of decision-making would help "scale paralysis" (i.e., find right scale for analysis and data-gathering).
- Needed are communications between those collecting and applying data to understand scale.
- Explore/extend power-law scaling relationships for various definitions of cities and urban characteristics in multiple dimensions.
- Explore the interannual and seasonal dynamics of urban phenomena through phenologies, UHI, run-off, water use, power use, etc.
- Explore the deviations from scaling relationships: where, when, why, how, etc.
- Calibrate and validate in data rich environments and then assess robustness of relationships by withholding available data.

TYPOLOGY of CITIES

- Income is clearly not enough in this goal. In many cases, it is more interesting to explore economic composition in cities.
- Cultural background is important.
- The morphology of cities.
- We need to introduce the perspective of the stakeholder; a typology needs to capture local contextual conditions.
- We need a dynamic view that introduces where you are and where you want to be. So processes of change have to be represented.
- What data can support this type of a typology? Some of the basic data do exist. More can be gained by RS – but how can it be best used?
- We want to try to do this matching of typology and data as researchers; this is not something that we want to ask the cities to do themselves although they can.
- We need to understand dependencies across pixels; can we map such a structure?
- Couple this exercise with the grand data challenges. Also very important, what is the end question?
- Several 'sustainability' variables can play prominent roles such as wealth per unit of energy input (proxy for efficiency).
- There is a lot of data out there (and a lot that can be readily built) so the main limitation is not identified there.
- What is important is an adaptive typology (a 'pick-and-choose' typology). In particular, one can view those as chips in a necklace (an efficiency chip, a form chi or a

vulnerability chip). These typologies need to capture complex dynamics and feedbacks – e.g., climate changes, the ecoregions that cities exist in.

- We need to explore the value added of the temporal dimension (e.g., the Landsat record).
- A main 3 category topology we can use involves fiscal, socioeconomic and environmental dimensions.
- Develop a spectral library of urban materials in order to identify types of materials – but there are also problems, e.g., dust or roofs covered with gardens leading to inaccuracies.
- Next steps: 3D, thermal data in higher resolution, more work from RS professionals through adequate funding.

URBANIZATION SCENARIOS

- It is important to identify key factors to provide a basic framework for building urbanization scenarios. Such framing should occur through engagement with stakeholders. The identified factors provide input to model development or selection to insure the model can represent range of scenarios. Identification of factors can be top down, higher level of government establishing basics of scenario, or this can be bottom up with discussion among stakeholders.
- One approach is to develop basic information about general issues as to assist stakeholders in selecting important factors. Also there is a need to engage stakeholders in discussion of what was important for future and then explore range of scenarios.
- Purposes of urbanization scenarios include:
    - Explore policy questions;
    - Scenarios can be used as a basis to facilitate dialogue between stakeholders that may not have occurred, perhaps where there are differing positions, such differing positions occur best in larger groups to diffuse some of the disagreement.
- Scenario constructions should start with the stakeholders' engagement. It is difficult to get stakeholders to consider the future in another context other than the present. Envisioning scenarios should include visualization and stories.
- Ranges of drivers have different importance at different scales.
- Measurements on population, governance, GDP growth et al., need to be considered when creating urbanization scenarios. A two by two box of population and GDP growth could be used to formulate urbanization scenarios in the city, regional and even global level.
- When we build urbanization scenarios, the following crucial drivers for future change which are varying and depending on scale need to be examined and included thoroughly: integration into the world system, rural – urban integration, population growth, income growth, connectivity, feedback loops of GEC (success of responses), governance (corruption), neoliberalism, level of FDI – global capital flows, institutions – legal, income inequality, resources, health, transportation, path dependence / existing density, education, local hazards, etc.