Caveats for Remote Sensing of Urban Areas

Panel Contribution to the PERN Cyberseminar on Urban Spatial Expansion by Christopher Small, Lamont Doherty Earth Observatory, Columbia University, Email: small @LDEO.columbia.edu

In the study of urban systems it may be useful to consider some of the dualities we must contend with. Specifically:

Duality of Process:
    Physical – processes that can be described by relatively simple physical laws.
    SocioEconomic – processes involving collective and individual human actions.

Duality of Inquiry:
    Observation – data collection and analysis
    Theory – development of theory and implementation of models

Duality of Representation:
    Cellular – representing actions and physical states of individual components
    Aggregate – representing measurable consequences of aggregations of individuals

Keeping in mind the distinctions and continua between the poles of each duality can simplify some problems. The distinctions are especially important when using physical measurements to address non-physical questions. John Hasse provided an excellent discussion of some of the issues related to representation. I have been asked to comment on some of the methodological and measurement issues, specifically related to remote sensing of urban areas.

Focusing on observation by remote sensing (as opposed to in situ measurement), it is important to consider some of the inherent caveats of the tools. The benefits of remote sensing are well known: consistent, synoptic, global coverage at multiple spatial and temporal resolutions. The caveats are less well known and this often leads to serious inaccuracies and misinterpretations. These caveats are related to the physical processes involved in making the measurements. Rather than launching into a discussion of orbital dynamics, radiative transfer and spatial analysis, I will try to briefly summarize a few concepts worth considering when trying to extract information from remotely sensed measurements.

1) *Physical properties and non-physical characteristics*. Remotely sensed information is derived from measurements of physical quantities (e.g. color, roughness, height, temperature) – generally using electromagnetic radiation. Some physical properties can be inferred from these measurements (to varying degrees of accuracy), others cannot. When attempting to quantify non-physical characteristics with indirect physical measurements it is worth asking whether or not the characteristic has unique physical properties. In many cases, they do not. For example, population density cannot generally be measured with

electromagnetic radiation. Some proxies for population density (e.g. land cover change) can be inferred from remotely sensed measurements but not always uniquely. The distinction is important.

2) *Scale-dependent heterogeneity*. By necessity, an individual image pixel represents a single measurement of some physical quantity. However, a pixel corresponds to a finite area (generally elliptical – never actually square) on the ground. The surface within that finite area is rarely compositionally homogeneous. The measurement associated with a single pixel is generally an unevenly weighted average of heterogeneous properties within the pixel footprint. Most pixels are "mixed pixels" but most thematic classification algorithms that produce maps from images are predicated on the assumption of homogeneity. This is why most of these algorithms produce notoriously inaccurate results when used to classify urban areas. Most urban areas are compositionally and spectrally heterogeneous at different spatial scales. In fact, comparative analyses of urban reflectance suggest that heterogeneity is the only spectral property common to many urban areas. Mixture models can represent the land surface as continuous fields of endmember fractions (e.g 40% vegetation, 40% soil, 20% water) more accurately than thematic classifications in which each pixel is a member of one, and only one, class. It is necessary to consider scale and heterogeneity in physical delineation of urban areas.

3) *Spectral and textural information*. Urban areas can often be recognized visually in remotely sensed imagery because of differences in reflectance (color) and spatial patterns (texture). Another reason why thematic classifications often fail to discriminate features that can be detected visually is because most thematic classification algorithms consider each pixel in isolation from its neighbors. Images also contain textural information related to the spatial variability in pixel brightness. The eye/brain system relies on both color and texture to discriminate objects. Analyses that combine spectral and textural information make better use of the available information. The tools are available but rarely used together.

4) *Combined properties from different measurements*. Because of their compositional heterogeneity at different spatial scales, urban areas have few unique physical properties that can be measured remotely. However, the combination of multiple non-unique properties can sometimes be unique, or nearly so. Combining remotely sensed measurements of different quantities from different sensors can provide a more accurate map than could be derived from any of the measurements alone

More detailed discussions and graphic examples of these points are available online at www.LDEO.columbia.edu/~small under the Research link.