International Journal of Applied Earth Observation and Geoinformation 7 (2005) 249–252

INTERNATIONAL JOURNAL OF APPLIED EARTH OBSERVATION AND GEOINFORMATION

www.elsevier.com/locate/jag

Editorial

Bridging scales and epistemologies: An introduction

Scale is the fundamental determinant of hierarchical structure (Levin, 1992). If something is not hierarchically structured, it is beyond our understanding (Simon, 1962). Therefore, a key to understanding the hierarchical structuring/patterning of complex systems – such as the planet upon which we live, and the societies we construct – lies in understanding the 'nature' of scale (Hay et al., 2002). In general terms, *scale* corresponds to one's 'window of perception'. More exactly, scale refers to the spatial dimensions at which entities, patterns, and processes can be observed and characterized. Thus, if one changes the scale at which a scene is viewed, one effectively changes (perceived) reality (Hay et al., 2003). Furthermore, every scale reveals information specific to its level of observation (Marceau, 1999). As a result, these concepts have important implications when conducting any scientific assessment, because the scale at which analysis is undertaken, significantly influences the problem definition and the corresponding results. More over, no single scale is sufficient for assessing the varying sized, and spatially arranged components on the planet, a society, or in any complex system. Therefore, to appropriately monitor, model, and manage these environments a multi-scale (i.e., more than a single scale) approach is necessary (Hay and Marceau, 2004).

Ecologists define scale as having two components: *grain* and *extent*. Grain corresponds to the smallest spatial sampling units used to gather a series of observations. Extent is the total area over which observations of a particular grain are made (O'Neill and King, 1998). In cartography, scale represents the ratio of a distance on a map to the corresponding distance on the ground. While in remote sensing, the spatial resolution of an image represents the surface on the ground or the spatial sampling increment from which (integrated) values are collected and registered by the sensor. The term *scaling* is often associated with multi-scale analysis, and refers to translating information from one scale to another. Though many individual methods and approaches exist, this is generally conducted in one of two ways (Bierkens et al., 2000). *Upscaling* refers to 'bottom-up' approaches that use information at a fine scale to derive information at a coarser scale; thus, information tends to be lost in the upscaled representation due to generalization. *Downscaling* refers to 'top-down' approaches that decompose information at one scale into its constituents at finer scales. This often results in information redundancy and increased storage requirements.

Due to the non-linearity inherent to complex systems, scaling poses a serious challenge, as significant errors can result when data are arbitrarily scaled across domains (Gardner et al., 1982; King, 1990). As a result, scaling is part of what is referred to as the 'scale problem' (Marceau and Hay, 1999). In the natural sciences (Marceau, 1999), this problem essentially encompasses two complementary components that may be expressed by the following questions:

- What is the appropriate spatial scale for the study of a particular (geographically based) entity or process?
- How can we adequately transfer information from one spatial scale to another?

In an effort to better understand these and other scale related challenges, the Millennium Ecosystem Assessment (MA) organized the international conference 'Bridging Scales and Epistemologies: Linking Local Knowledge with Global Science in Multi-Scale Assessments' on March 17–20, 2004, at the Bibliotheca Alexandrina, Alexandria, Egypt (MA, 2005a). The MA is an international work program, launched in June

0303-2434/$ – see front matter
doi:10.1016/j.jag.2005.06.004

2001 by UN Secretary-General Kofi Annan (and completed in March 2005) that was '... designed to meet the needs of decision makers and the public for scientific information concerning the consequences of ecosystem change for human well-being and options for responding to those changes' (Reid, 2004). It represents a 4 year, US$ 24 million effort that includes the work of more than 1360 authors from 95 countries, who have participated in 4 expert work groups preparing the global assessment (MA, 2005b), with hundreds more involved in more than 30 sub-global assessments (MA, 2005c).

The MA '... focuses on ecosystem services (the benefits people obtain from ecosystems), how changes in ecosystem services have affected human wellbeing, how ecosystem changes may affect people in future decades, and response options that might be adopted at local, national, or global scales to improve ecosystem management and thereby contribute to human well-being and poverty alleviation' (MA, 2005d). As a result, it includes partnerships with UN agencies, international scientific organizations, development agencies, along with guidance from private sector and civil society groups. The MA will also help to meet assessment needs of the Convention on Biological Diversity, Convention to Combat Desertification, the Ramsar Convention on Wetlands, and the Convention on Migratory Species, as well as other users (Reid, 2004).

Two pioneering aspects distinguish the MA from previous global assessments. First, it was conducted as a 'multi-scale' assessment (MA, 2005h) with integral sub-global assessment components conducted at local community, watershed, national, and regional scales—in addition to the global scale. Second, it incorporates both *traditional knowledge* and *scientific information* within the assessment process (Reid, 2004). These two aspects are fundamentally linked. This is because an effective local assessment must rely on traditional knowledge of local ecological and social systems, and a global assessment must rely on data and information gathered through remote sensing and scientific research (Willbanks, 2004). Therefore, if local and global assessments are to be effectively combined within a multi-scale assessment, mechanisms must be created that enable these different 'ways of knowing the world' (or epistemologies) to be integrated. However, operationalizing these mechanisms poses major theoretical and methodological challenges. The exploration of these challenges under the conference themes, '*Methodologies for Integrating Data across Multiple Scales*' and '*Understanding Cross-Scale Interactions*' represented a primary goal of the Alexandria conference.

To better understand these challenges and provide solutions for them, this special issue consists of seven papers – carefully selected from these conference themes, and expanded upon – that cover a broad range of Earth observation data types, methodological approaches, and spatio-temporal dimensions. For simplicity, we have organized these contributions within two sections. The first four papers emphasise research conducted over at least two different *temporal* scales, while the last three papers focus on studies involving at least two different *spatial* scales. Similarly, each section begins with papers that cover broad spatial scales (i.e., individual countries), and concludes with papers representing finer scales (i.e., local watersheds, and individual trees).

1. Emphasis: temporal scales

- The first paper, by Marc Metzger et al., presents a new multi-disciplinary multi-scale framework for assessing the *vulnerabilities* of ecosystems and ecosystem services to global change over a 90-year period. By so doing, important policy-relevant questions such as 'what are the main regions or sectors that are vulnerable to global change?' and 'how do the vulnerabilities of two regions compare?' can be addressed. A statistically derived European environmental stratification forms a key element in this vulnerability assessment that, when linked to other quantitative environmental stratifications, allows for comparisons to be made using data from different assessments and spatial scales.
- The second paper, by Chris Davis and Tim Schaub describes the use of three new metrics applied to remote sensing data, census data, and permit data (over a 10–15 year period) in order to map *urban sprawl* in the Pacific Coast Region of North America. They also discuss and compare the social, economic, and political reasons for this phenomenon within a study area that spans two nations, three state/provincial governments, and dozens of cities.
- The third paper, by Hamisai Hamandawana et al., illustrates how archival, historical and remote sensing data (from both commercial and declassified Cold War intelligence sources) can be integrated to generate a (>150 years) temporal data base for long-term environmental monitoring of the Okavango Delta, in northern Botswana, Africa—the world's largest Ramsar site. A detailed overview of the historical and environmental components of this important site is also provided.

- The fourth paper, by Xu Jianchu et al., explores the spatial and temporal dynamics of land use in the Xizhuang watershed of Yunnan, Southwest China, by comparing aerial photographs (1987) and Aster satellite data (2002). However, unlike typical multi-temporal classifications, this research represents a strong example of how traditional knowledge and scientific information can be integrated for enhanced assessments—as outlined by the MA. This is achieved by drawing on socioeconomic and spatial information collected from household interviews, participatory social mapping, land use mapping, and policy review. The result is a rich narrative that illustrates how socio-political decisions made at a national level, can have adverse effects on local populations, their way of life, and their surrounding environment.

2. Emphasis: spatial scales

- The fifth paper, by Liangzhi You and Stanley Wood introduces a new entropy based model that provides plausible high-resolution (municipal scale) estimates for the spatial distribution of crops from coarse level (geopolitical or national scale) crop production statistics. This is achieved by allowing for the judicious integration of diverse types, and scales of spatial information including, crop production statistics, farming system characterization, satellite-based land cover maps, biophysical crop suitability assessments, and population density. An example is presented in which Brazilian state level production statistics are used to generate pixel level crop data for eight crops.
- The sixth paper, by Trevor Quinn et al., examines the concept of *scale incompatibility* by comparing different simulations of watershed processes based on conventional soil maps, and simulations based on detailed soil information over different simulation scales. Two different modelling approaches are evaluated (over a 356-day period) for two watersheds in western Montana, USA.
- The seventh paper, by Geoffrey Hay et al., describes a new integrative methodology for automatically *upscaling* and *segmenting* a high-resolution IKONOS forest scene into components that cognitively correspond to image-objects ranging from individual trees to forest stands. Segmentation is based on automatically extracted spatial measures that are explicitly related to the varying sized, shaped, and spatially distributed scene components. Seven different spatial resolutions are examined ranging from 1.0 m to 10 m. They also describe how this method may be used for computer assisted forest inventory mapping, and present a simple model to extend this method over coarser scales. Analysis is conducted in the Sooke watershed on southern Vancouver Island, BC, Canada.

We invite you to explore these papers and welcome your feedback. We additionally invite you to sample the extensive documentation and recommendations available at the MA website (MA, 2005e), which includes over 25 presentations and 90 short papers from the Alexandria conference (MA, 2005f), as well as global and sub-global assessments, and 15 other synthesis reports (MA, 2005g). We express thanks to Dr. Alfred Stein, for his support as we coordinated manuscripts from various locations around the globe, and thank the authors for their contributions. We gratefully acknowledge the efforts of 22 peer reviewers whose participation has strengthen the content of this special issue.

References

Bierkens, M.F., Fink, P., Peter, A., Willigen, P.De., 2000. Upscaling and Downscaling Methods for Environmental Research. Developments in Plant and Soil Sciences, vol. 88. Kluwer Academic Publishers, London, p. 199.

Gardner, R.H., Cale, W.G., O'Neill, R.V., 1982. Robust analysis of aggregation error. Ecology 63 (6), 1771–1779.

Hay, G.J., Marceau, D.J., 2004. Multiscale object-specific analysis (MOSA): an integrative approach for multiscale landscape analysis. In: de Jong, S.M., van der Meer, F.D. (Eds.),Remote Sensing and Digital Image Analysis. Including the Spatial Domain. Remote Sensing and Digital Image Processing, vol. 5Kluwer Academic Publishers, Dordrecht, pp. 71–92 (Chapter 3).

Hay, G.J., Blaschke, T., Marceau, D.J., Bouchard, A., 2003. A comparison of three image-object methods for the multiscale analysis of landscape structure. Photogrammetric Eng. Remote Sens. 57, 327–345.

Hay, G.J., Dubé, P., Bouchard, A., Marceau, D.J., 2002. A scale-space primer for exploring and quantifying complex landscapes. Ecol. Modell. 153 (1–2), 27–49.

King, A.W., 1990. Translating models across scales in the landscape. Quantitative Methods in Landscape Ecology Springer-Verlag, pp. 479–517.

Levin, S.A., 1992. The problem of pattern and scale in ecology. Ecology 73, 1943–1967.

Marceau, D.J., 1999. The scale issue in the social sciences. Can. J. Remote Sens. 25 (4), 347–356.

Marceau, D.J., Hay, G.J., 1999. Remote sensing contributions to the scale issue. Can. J. Remote Sens. 25 (4), 357–366.

MA, 2005a. Bridging Scales Conference [http://www.maweb.org//en/about.meetings.bridging.aspx]. Last retrieved June 15, 2005.

MA, 2005b. Global Assessments [http://www.maweb.org/en/Products.Global.aspx]. Last retrieved June 15, 2005.

MA, 2005c. Sub-global Assessments [http://www.maweb.org/en/Products.Subglobal.aspx]. Last retrieved June 15, 2005.

MA, 2005d. MA Overview [http://www.maweb.org//en/About.Overview.aspx]. Last retrieved June 15, 2005.

MA, 2005f. MA Website [http://www.maweb.org]. Last retrieved June 15, 2005.

MA, 2005f. Bridging Scales Conference Proceedings [http://www.maweb.org//en/about.meetings.bridging.proceedings.aspx]. Last retrieved June 15, 2005.

MA, 2005g. Overview of Synthesis Products [http://www.maweb.org/en/Products.aspx]. Last retrieved June 15, 2005.

MA, 2005h. Ecosystems and Human Well-being: Multi-scale Assessments, Findings of the Sub-global Assessments Working Group. vol. 4, Island Press. 515 pp. [http://www.islandpress.org/books/detail.html/SKU/1-55963-186-4]. Last retrieved June 15, 2005.

O'Neill, R.V., King, A.W., 1998. Homage to St. Michael; or why are there so many books on scale? In: Ecological Scale Theory and Applications, Columbia University Press, pp. 3–15.

Reid, W., 2004. Bridging scales and epistemologies in the Millennium Ecosystem Assessment. In: The Proceedings of Bridging Scales and Epistemologies—Linking Local Knowledge and Global Science in Multi-Scale Assessments Alexandria, Egypt, March 17–20, 2004 [http://www.maweb.org/documents/bridging/papers/reid.walter.pdf]. Last retrieved June 15, 2005.

Simon, H.A., 1962. The architecture of complexity. Proc. Am. Philos. Soc. 106, 467–482.

Willbanks, T.J., 2004. How scale matters: some concepts and findings. Paper prepared for the conference: In: The Proceedings of Bridging Scales and Epistemologies—Linking Local Knowledge and Global Science in Multi-Scale Assessments Alexandria, Egypt, March 17–20, 2004 [http://www.maweb.org/documents/bridging/papers/Wilbanks.tom.pdf]. Last retrieved June 15, 2005.

Guest Editor
Geoffrey J. Hay *
Department of Geography, University of Calgary, 2500 University Drive N.W. Calgary, Alta., Canada T2N 1N4
*Tel.: +1 403 220 5584; fax: +1 403 282 6561
E-mail address: gjhay@ucalgary.ca

16 June 2005