

# Scale in Remote Sensing and GIS

Edited by

**Dale A. Quattrochi**

National Aeronautics and Space Administration  
Huntsville, Alabama

and

**Michael F. Goodchild**

University of California  
Santa Barbara, California



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**Cover:** Color composite image of processed Landsat Thematic Mapper image recorded September 14, 1989 over the central Amazon River approximately 50 km upstream from the town of Óbidos and 650 km downstream from the town of Manaus. The record flood of 1989 has receded approximately 2 m, the floodplain is draining, and flow is from left to right (west to east) in the main channel which is 4 to 6 km wide. The color of the main channel (red) indicates relatively high suspended-sediment concentrations in the water. The dark blue color indicates relatively clear water, and blue-green indicates tropical forest. Image processing completed by A. K. Mertes, Department of Geography, University of California, Santa Barbara. Raw image provided by R. Almeida Filho of INPE, Brazil.

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## Multiresolution Covariation Among Landsat and AVHRR Vegetation Indices

Lee De Cola

### INTRODUCTION

The treatment of data at multiple scales is well-established in the spatial analytical literature (Bian and Walsh, 1993; Franklin, 1994; Frank et al., 1994; Lambin et al., 1995) and is becoming increasingly common in broader discussions of biophysical and landscape processes (Meentemeyer and Box, 1987; Turner and Gardner, 1992). Quattrochi (1993) provides a "lexicon of scale" that presents the fundamental dimensions of the problem. I would rearrange his discussion by prioritizing the issues:

- Space: absolute and relative
- Measurement: resolution and extent
- Analysis: scaling and measures of spatial complexity (Stoms, 1994)
- Objects and processes: resolution element (fine level) and characteristic size (coarse level) (Cullinan and Thomas, 1992)

This organization begins with abstract space, which forms a framework for measurement that produces data to be analyzed at multiple resolutions for the characterization of processes and the identification of objects. In this chapter the first and last issues are not explored as the data are already given; the focus is more on technique than on characterization either of the landscape in general or of vegetation in particular.

The typical approach to scale issues argues that each phenomenon requires a specific scale of data for its characterization (Jensen, 1986). This book demonstrates how information from a range of scales is critical to the understanding of spatial processes. In keeping with Quattrochi's system, all data may be considered as

existing in a space of four conceptual dimensions, each with its unique characteristics:

- Space — continuous and unbounded (Getis and Franklin, 1987)
- Time — continuous and bounded in one direction (the future) (Peuquet, 1993)
- Feature — discontinuous and unbounded (Buttenfield, 1994)
- Scale — continuous and bounded in one direction (the finest available resolution) (Basseville et al., 1992)

This scheme augments the usual notion of features in space and time by highlighting the nature of scale itself as a hierarchical framework within which phenomena may be studied. Each of the first three dimensions presents us with (usually strongly related) scale issues. Moreover, time and scale have directionality. Time moves from past through present to future, and we have more confidence in historical data based on prior states of a system than in future projections. Scale moves from coarse to fine, and we become less certain of lower-level (finer) representations based on interpolations of spatial data than on higher-level generalizations. Finally, spatial scale itself is a continuum that reveals useful information about phenomena only when we look at multiple scales.

Nevertheless, the word “scale” will be avoided here because it has strict cartographic and loose physical meanings that are opposite in intent, and because the term is better constrained to references to some continuum (small to big) than applied to specific levels within the range. As this chapter is concerned with satellite data, the term “resolution” is used instead. The next sections formalize these ideas, introduce data to illustrate them, and then analyze the data. The chapter concludes with a broader view of this research.

### MULTIRESOLUTION ANALYSIS

Let  $l = 0, \dots, L$  be a resolution level, where larger values of  $l$  denote larger (coarser) physical resolutions of observation or analysis. Let a given dataset  $A_0$  consist of measurements made at some resolution considered to be level-0 for the available data (for example, for the Landsat thematic mapper (TM) level-0 is based on 30-m instantaneous field of view (Richards, 1986)). The integer index  $l$  will correspond to the relative physical size of the units of observation, in this case grid cells. The exploration of scaling in data is sometimes based on multiple levels of observations but usually depends upon the analysis of original data at multiple resolutions created by some kind of a generalization operator  $g(\ )$  that should not introduce artifacts into the data. Consider the production of  $A_1 = g(A_0)$  where  $A_1$  is some generalized version of  $A_0$ . This process can be repeatedly applied

$$g^2(A) = A_{l+2} = g(A_{l+1}) = g(g(A_l)) \quad (1)$$

to produce a recursively constructed data pyramid

$$\{A\} = \{A_l; l = 0, \dots, L\} \quad (2)$$

based on level-0 (Samet, 1989). There are many ways to generalize data, such as sampling, filtering, and averaging, which are appropriate for various kinds of objects and fields (Buttenfield and McMaster, 1991). In the present case the generalization is done by averaging  $2 \times 2$  non-overlapping windows (De Cola, 1994).

Table 1 describes a power-2 grid pyramid of size  $L = 10$  ( $2^L = 2^{10} = 1024$ ) based on 31.25-m data. The columns of the table show level  $l$ , which indexes the layers of the pyramid, the number of cells in each row (= number of cells in each column), and the size of each cell. Three types of data are also shown for reference, from 1000-m advanced very high resolution radiometer (AVHRR) cells, through 30-m Landsat TM, to 1-m digital orthophoto quad imagery. In this chapter the word grid is used to refer to imagery or raster data to convey the idea that these operations could be performed on any kind of rectangular array.

19  
21,229 Km  
earth  
Table 1 Description of Pyramids Used in this Chapter and Comparisons with Other Grid Data

Level	Cells in each row	Cell size (m)	Grid data examples	Typical regions
13	0.125	256,000		Chesapeake Bay
12	0.25	128,000		1 degree
11	0.5	64,000		
10	1	32,000		
9	2	16,000		1:24,000 USGS quad
8	4	8000		
7	8	4000		
6	16	2000		
5	32	1000	AVHRR	
4	64	500		
3	128	250		
2	256	125		
1	512	62.5		
0	1024	31.25	Landsat TM	
-1	2048	15.62		
-2	4096	7.81		
-3	8192	3.91		
-4	16384	1.95		
-5	32768	0.98	DOQ	

It should be noted that in  $E = 2$ -dimensional space,  $Vol$ , the volume of data (or number of cells, for example in bytes; see Light, 1986) of a pyramid is only  $1/3$  greater than that of its lowest level. This advantage is even greater for 3-dimensional pyramids, for which the additional size is only  $1/7$ . In fact, for any physical space of  $E$  dimensions, the ratio of the size of a pyramid and that of its lowest level is

$$Vol(\{A\})/Vol(\{A_0\}) = 2^E/(2^E - 1) \quad (3)$$

