Geostatistical Analysis of Multi-Scale Remote Sensing Images for Land Degradation and Desertification Monitoring

Elena V. Tarnavsky[1] and Molly E. Brown[2]
[1]King's College London, The Strand, London WC2R 2LS, United Kingdom
[2]NASA Goddard Space Flight Center, Code 614.4, Greenbelt, MD 20771, United States

Abstract

Through the interaction of climate, land, and vegetation cover, desertification processes operate at fine spatial scales, yet policies are implemented at the regional scale [1], [2], [3]. This problem is commonly addressed through spatially intensive field surveys of vegetation cover and analysis of remote sensing imagery at relatively fine spatial scales, in which substantial success has been achieved [4], [5]. However, the challenge has been to acquire and validate fine-scale vegetation cover data (typically from multi-day NDVI composites) for the large spatial extents required for regional resource management and policy implementation. To address this challenge, we evaluated the comparability of multi-sensor remote sensing images and their potential for simultaneous and/or interchangeable use in enhancing both the spatial and temporal aspects of explanatory and predictive land degradation and desertification models.

Goals and Objectives

To achieve our goals, we explored the spatial structure and behavior of vegetation cover in moderate (few hundred meters) to coarse (one to few kilometers) scale images from the MODIS and AVHRR imaging instruments. Such images provide the required spatial coverage for assessment of land degradation and desertification [6], [7], [8], [9], [10]. Specifically, our goals were to: (a) derive a quantitative measure of vegetation cover structure and variability at different spatail scales, and (b) compare the moderate-scale spatial properties of vegetation cover to those at coarser scales of observation. In achieving these goals, we also investigated the potential for interchangeable use of images at different spatial scales for quantitative description of the spatial structure of typically sparse vegetation cover in the Mediterranean region of Southern Europe (Spain) and Northern Africa (Algeria and Tunisia) that is prone to land degradation and desertification (Figure 1).

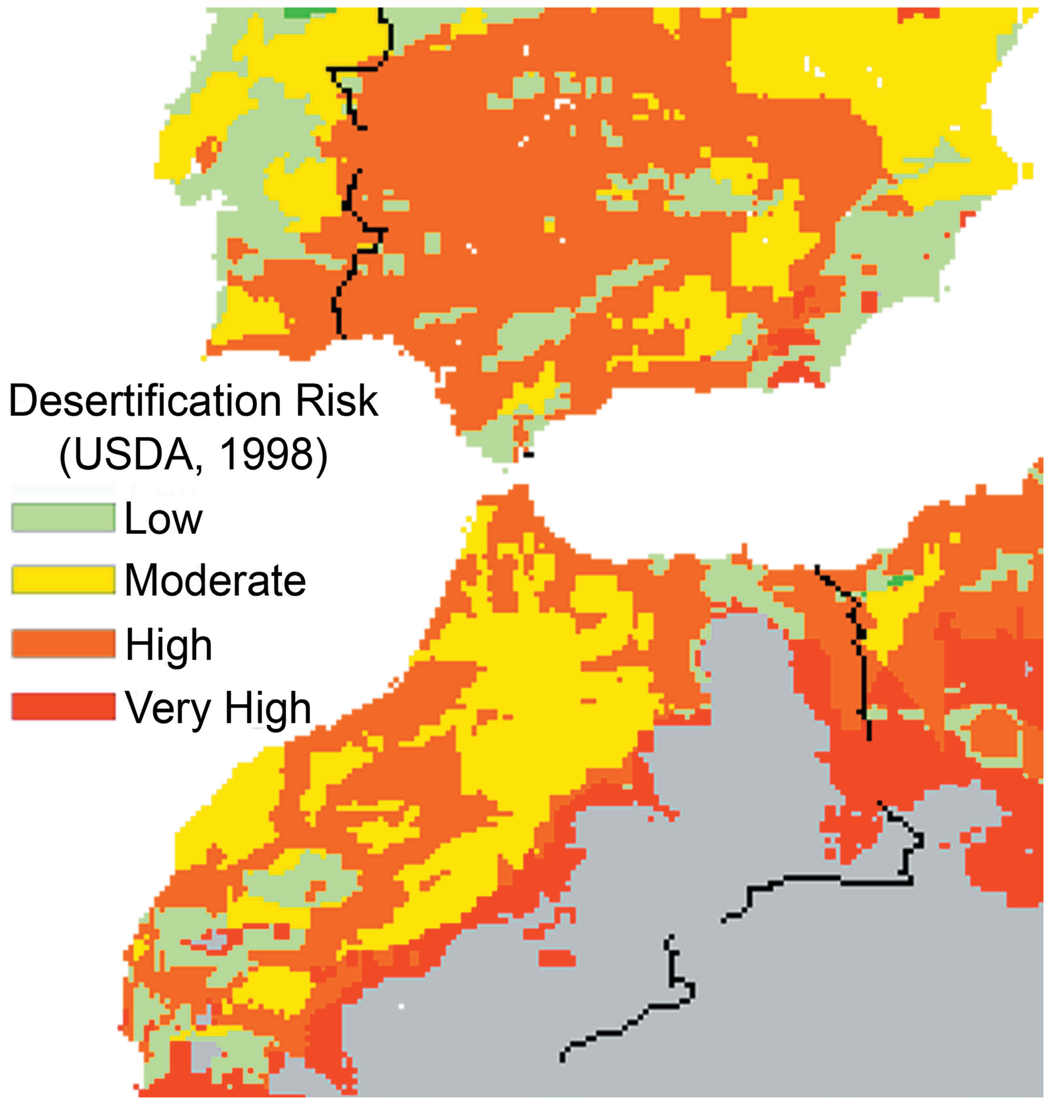

Figure 1. Desertification Vulnerability Map of Southern Spain and Portugal, Europe, and Morocco, North Africa. The world map of desertification vulnerability is prepared and updated by the U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Division, World Soil Resources, in Washington, D.C., 1998.

Data and Methods

In order to assess the nature and behavior of spatial structures, we subjected the moderate and coarse resolution images to geostatistical analysis of spatial variance [11]. For this purpose, the normalized difference vegetation index (NDVI) products from the NOAA-AVHRR and MODIS/Terra imaging instruments were used as these are related to the spatial distribution of vegetation cover in the study region. These instruments have different sensor characteristics and image processing chains (Table 1). We used multi-day NDVI composites from the AVHRR GIMMS group generated at 8 km spatial resolution, and the following MODIS NDVI products from the EOS Data Gateway: MODIS 1 km (MOD13A2), 500 m (MOD13A1), and 250 m (MOD13Q1) as shown in Figure 2. Omnidirectional semi-variograms were derived from each global NDVI product subset. The cross-scale comparison of spatial structure and variability was based on the semi-variance value for a series of increasing lag distances, as well as on the range and sill values of the AVHRR and MODIS empirical variograms shown in Figure 3.

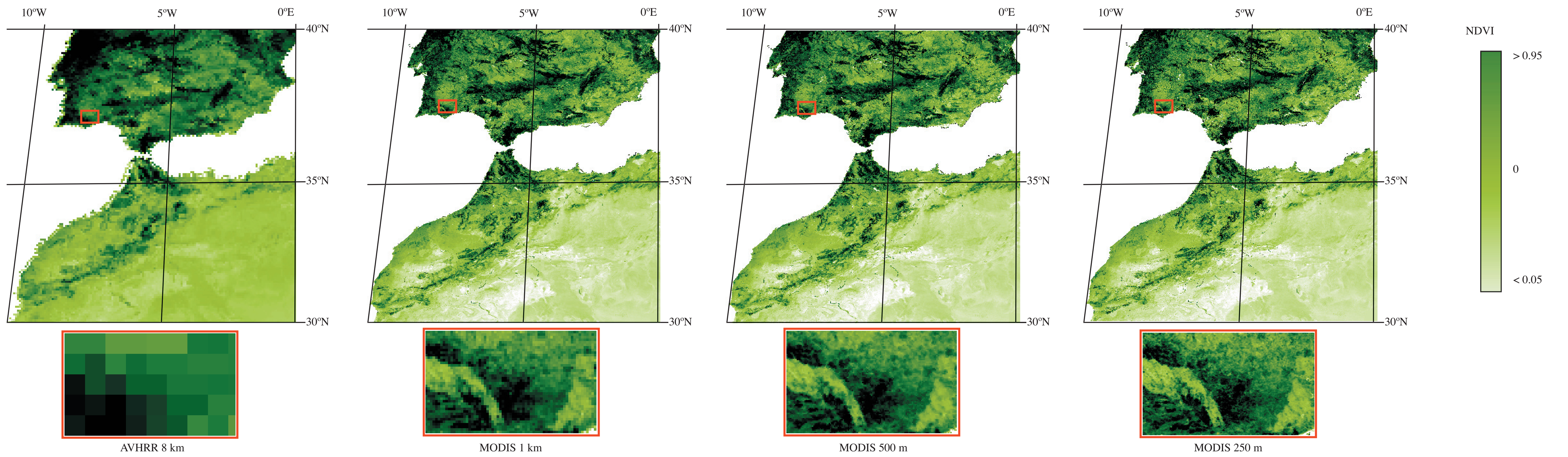

Figure 2. Normalized Difference Vegetation Index (NDVI) Maps of the Study Region (Southern Spain and Portugal, and Morocco) with detailed views of the AVHRR 8-km, MODIS 1-km, 500-m, and 250-m multi-day NDVI composites covering nearly 3000 square kilometers.

Table 1. Sensor Characteristics

Sensor / Sensor Characteristics	NOAA AVHRR	MODIS/Terra		
NDVI data source	AVHRR GIMMS	MOD13A2	MOD13A1	MOD13Q1
Spatial Resolution of NDVI product	8 km	1 km	500 m	250 m
Approximate Subset Size (pixels)				
Pixel Size (m)	1100	927	463	232
View Angle (across track)	55 degrees	55 degrees	55 degrees	55 degrees
Swath Width (km)	2800	2330 km across track, 10 km along track		
Quantization (Radiometric Resolution)	10 bits	12 bits	12 bits	12 bits
Compositing	15-day	16-day	16-day	16-day
a. Period, From-To (mm/dd, yyyy)	9/1–9/15, 2001	8/29–9/13, 2001	8/29–9/13, 2001	8/29–9/13, 2001
b. Method	MVC	CV-MVC	CV-MVC	CV-MVC
Waveband Width				
a. Red (micrometers)	0.58-0.68	0.62-0.67	0.62-0.67	0.62-0.67
b. Near Infrared (micrometers)	0.73-0.98	0.84-0.88	0.84-0.88	0.84-0.88
c. Thermal	yes (not used in NDVI)		yes (used in NDVI)	
Orbit	sun-syncrhronous	sun-synchronous	sun-synchronous	sun-synchronous
a. Eccentricity	circular	circular	circular	circular
b. Altitude (km)	833	705	705	705
c. Inclination (degrees)	98.8	98.2	98.2	98.2
d. Configuration/Scan Rate (rpm)	360	20.3 (cross track)	20.3 (cross track)	20.3 (cross track)
e. Scan Rate (scans/sec)	6	1.477	1.477	1.477
f. Orbit Period (minutes)	101.2	99	99	99
g. Repeat Cycle (days)	9	16	16	16
h. Passages Per Day (Equatorial/Mid Lat)	2/4	4/4	4/4	4/4

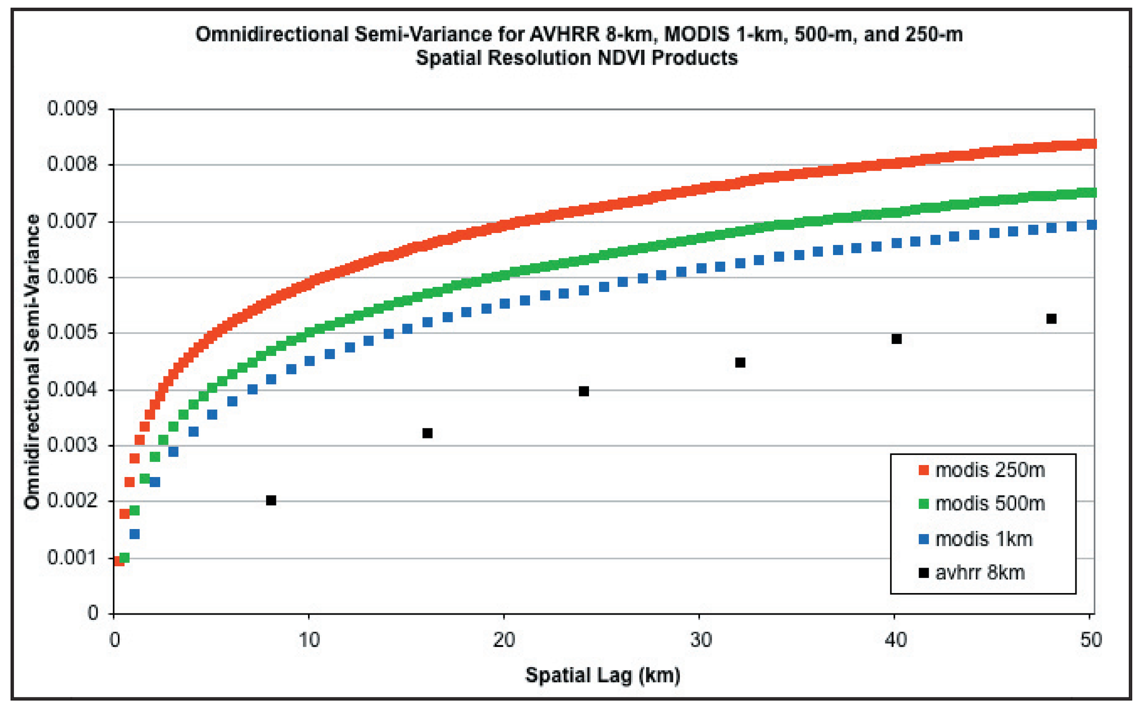

Figure 3. Omni-directional Empirical Semi-Variogram Curves for 8-km AVHRR and 1-km, 500-m, and 250-m MODIS NDVI's.

Summary of Results

The analysis confirmed that information from the moderate resolution images (250 m and 500 m MODIS) could be used to describe the spatial pattern of vegetation cover in coarse resolution images (1 km MODIS and 8 km AVHRR). These results suggest that moderate resolution images can be useful for coarse-scale parameterization of variables through the quantitative description of spatial heterogeneity based on variogram analysis of MODIS and AVHRR NDVI products. This study makes a valuable contribution to the domain of cross-scale investigations in that it examines real-world, multi-source images rather than spatially aggregated imagery from a single imaging instrument. Most notably, this study applies directly to the practical challenges of complex land degradation and desertification monitoring in semi-arid environments, thus allowing scientists and resource managers to work with a greater variety of remote sensing images.

References

[1] LOBO, A., MOLONEY, K., OSCAR, C., AND CHIARIELLO, N., 1998. Analysis of Fine-Scale Spatial Pattern of a Grassland from Remotely Sensed Imagery and Field Collected Data. Landscape Ecology 13, pp. 111–131.
[2] MULLIGAN, M., 1998. Modelling the Geomorphological Impact of Climatic Variability and Extreme Events in a Semi-Arid Environment. Geomorphology 24, pp. 59–78.
[3] MAZZOLENI, S., DI PASQUALE, G., MULLIGAN, M., DI MARTINO, P., AND REGO, F., (eds.), 2004. Recent Dynamics of the Mediterranean Vegetation and Landscape. John Wiley: Wiltshire, Great Britain.
[4] CAMACHO-DE COCA, F., GARCIA-HARO, F.J., GILABERT, M.A., AND MELIA, J., 2004. Vegetation Cover Seasonal Changes Assessment from TM Imagery in a Semi-Arid Landscape. Int. J. Remote Sensing 25, pp. 3451-3476.
[5] DREGNE, H.E., 1983. Desertification of Arid Lands. In: Advances in Desert and Arid Land Technology and Development, Volume 3. Harwood Academic Publishers: New York.
[6] GOETZ, S.J., 1997. Multi-Sensor Analysis of NDVI, surface temperature and biophysical variables at a mixed grassland site. Int. J. Remote Sensing 18, pp. 71-94.
[7] HUETE, A., AND DIDAN, K., 2004. MODIS Seasonal and Inter-Annual Responses of Semiarid Ecosystems to Drought in the Southwest U.S.A. Int. Geosciences and Remote Sensing Symposium 3, pp. 1538-1541.
[8] KOGAN, F., GITELSON, A., ZAKARIN, E. SPIVAK, L., AND LEBED, L., 2003. AVHRR-Based Spectral Vegetation Index for Quantitative Assessment of Vegetation State and Productivity: Calibration and Validation. PE&RS 69, pp. 899-906.
[9] SONG, X., SAITO, G., KODAMA, M., AND SAWADA, H., 2004. Early Detection System of Drought in East Asia Using NDVI from NOAA/AVHRR Data. Int. J. Remote Sensing 25, pp. 3105-3111.
[10] WANG, G., GERNER, G., AND ANDERSON, A.B., 2004. Up-Scaling Method Based on Variability-Weighting and Simulation for Inferring Spatial Information Across Scales. Int. J. Remote Sensing 25, pp. 4961-4979.
[11] JUPP, D.L.B., STRAHLER, A.H., AND WOODCOCK, C.E., 1989. Autocorrelation and Regularization in Digital Images: II. Simple Image Methods. IEEE Transactions on Geoscience and Remote Sensing 27, pp. 247-258.