Accuracy Sampling Design Bias on Coarse Spatial Resolution Land Cover Data in the Great Lakes Region (United States and Canada)

John S. Iiames, PhD

U.S. EPA, Office of Research & Development, National Exposure Research Laboratory, Environmental Sciences Division, Research Triangle Park, NC

ABSTRACT

A number of articles have investigated the impact of sampling design on remotely sensed land-cover accuracy estimates. Gong and Howarth (1990) found significant differences for Kappa accuracy values when comparing pure-pixel sampling, stratified random sampling, and stratified systematic unaligned sampling. This study compares accuracy assessment results for land-cover derived from 2007 Moderate Resolution Imaging Spectroradiometer (MODIS) 250 m normalized difference vegetation index (NDVI) time-series data for the Great Lakes Basin (GLB), USA. Here, two sampling schemes are compared: (1) pure-pixel sampling (within a 3 x 3 window) and (2) isolated independent pixel sampling (i.e. 'edge pixels'). MODIS spectral characteristics typically 'bleed' from adjacent pixels spectrally contaminating assumed pure 'edge pixels'. This study will explain the possible bias by inclusion of these fringe pixels within the assessment process. Our study focuses on the Northern Lakes and Forests Level III Omernik ecological region (115,934 km^2) south of Lake Superior and existent within three states (Michigan, Wisconsin, and Minnesota).

INTRODUCTION

Studies of accuracy assessments of land-cover derived from high resolution imagery (e.g. Landsat ETM+ 30 m ground surface distance (GSD)) have shown that sample placement within homogeneous areas resulted in the highest accuracies when compared to assessments where sample placement disregarded the 'homogeneous' area criterion (Gong and Howarth, 1990; Plourde and Congalton, 2003). Plourdes and Congalton (2003) found that sampling method (i.e. systematic, stratified random sampling, etc.) had less of an effect on accuracy than did sample placement. Our objective with this study is to compare two sampling techniques for sample placement in the accuracy assessment process for coarse spatial resolution derived imagery. Here, land-cover generated from the MODIS-NDVI 250 m time-series data was assessed via pure-pixel and edge-pixel sampling.

Distortion in MODIS NDVI data is affected by a number of sources, primarily by sensor-based and atmospheric causes. Geometric deformation is introduced by instrument viewing geometry, instrument perturbation relative to the surface, surface relief, and the curvature of the earth (Wolfe et al., 1998). The MODIS swath width is approximately 2,340 km where nadir GSD approaches 250 m. However, off-nadir the observation angle approaches 55° at the extreme edge of the swath causing pixel distortion. Gridding image observations into the 250 m output grid produces other types of variability in that both observations and grid cells have different dimensions and are misaligned. Wolfe et al. (1998) found that populating output image grids introduce artifacts where grid cells and observations do not exactly match.

Atmospheric attenuation (i.e. scattering and water vapor absorption) also degrades the NDVI signal with turbid atmospheres resulting in decreased NDVI values (Huete et al., 1999). Atmospheric correction algorithms applied to the NDVI product do minimize the effect of atmospheric degradation on this data. Huete et al. (1999) notes however that some residual aerosol contamination may occur due to the coarse resolution (20 km) of the aerosol product. Another source of variation occurs during this process. Bi-directional reflectance effects over the canopy surface scatter solar radiation anisotropically and can seriously affect vegetation indices. The MODIS Science Team has minimized this effect by developing compositing algorithms that model the bi-directional reflectance emanating from vegetative canopies, however data quality is reduced at the swath edges.

STUDY AREA

The GLB is one of the most heavily industrialized regions in North America, but also a region that supports a variety of unique ecosystem services that include numerous intensively managed land-use activities. Agricultural production in the GLB represents 7% of US and 25% of Canadian agricultural production. Through population growth and redistribution, urban expansion, and loss of natural areas to development, numerous human-induced alterations have occurred resulting in substantial land degradation, deterioration of air and water quality, degradation of watershed habitats, and land-cover change trajectories that have substantially altered biodiversity and ecological services (Lunetta et al., 2009). Our study focuses on the Northern Lakes and Forests Level III Omernik ecological region (115,934 km^2) south of Lake Superior and existent within three states: Michigan, Wisconsin, and Minnesota (Figure 1). The Northern Lakes and Forests Ecoregion is characterized by moist low boreal and sub-humid transitional low boreal ecoclimates and consists of mixed conifer and deciduous forests and wetlands.

METHODS

DATA ACQUISITION: Eight years (2000-2007) of MODIS (MOD13Q1) 16-Day composite NDVI data was downloaded from the USGS EROS Data Center. NDVI data were clipped to the Great Lakes study boundary then re-projected from native sinusoidal to an Albers Equal Area Conic projection. A 250 m x 250 m grid multilayer image stack was then generated.

CLASSIFICATION: This classification was designed only for forest, grass, and shrub landcover types. Major cropland types were mapped for the Great Lakes Basin (GLB) using a neural network classification for 2007 (Shao et al., 2010). A preliminary attempt to classify the 'urban' class proved ineffective across the entire ecoregion. Utilizing MODIS data created many false positives with respect to this particular land-cover class. Therefore, in order to focus solely on natural vegetation, the water, agriculture, and urban cover types were masked out of the imagery. Masks were created from the 2001 National Land Cover Dataset (NLCD) by populating corresponding MODIS-NDVI 250 m grid cells with the 30 m resolution NLCD pixels. Simple majority calls (i.e., > 50% of one NLCD land-cover type) within each 250 m cell identified cells of that particular class, thereby facilitating the creation of the land-cover masks previously described. These masks were then applied to the study area in order to isolate the natural vegetation components. Hyperspectral image classification techniques were then applied to the MODIS-NDVI dataset. Using temporal variation as a surrogate for optical reflectance spectra, the Spectral Angle Mapper (SAM) algorithm was used to differentiate the vegetated MODIS-NDVI pixels (Figure 2). The SAM uses an n-dimensional angle vector to match pixels to provided spectra (Knight et al., 2006). The algorithm determines the similarity of two spectra by computing the angle between the spectra (Knight et al., 2006).

ACCURACY ASSESSMENT: Accuracy assessment sample site selection was made by generating random samples stratified by land-cover class. NLCD classes identified as 100 percent pure (i.e. one land cover class only) per 250 m MODIS-NDVI cell were identified. National Agriculture Imagery Program (NAIP) 2006-2007 Digital orthophoto quadrangles (DOQs) were downloaded from the USDA Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/) for the area of interest. Grid cells (250 m) corresponding to MODIS-NDVI grid cells were overlaid on each DOQ to check for cover type and position within homogeneous areas. Grid cells centered within a 3 x 3 window labeled as 100 percent one cover type were noted as to those grid cells isolated from similar cover types. A total of 568 grid cells were identified representing the major landcover types (deciduous, coniferous, mixed, bare, and grasslands). Wetlands were classified as deciduous, coniferous, or mixed. Error matrices were created for each of the two methods ('pure pixel' versus 'edge pixel'). To test whether the classifications were better than a random classification, a Kappa analysis (KHAT statistic generation) was performed on both matrices. The asymptotic normal distribution exhibited by the KHAT statistic allows for the testing of significance based on the standard normal distribution (Congalton and Green, 1999). Between matrix differences were compared by analyzing overall accuracy, normalized accuracy, and the KHAT statistic for both matrices.The accuracy assessment was performed only on the Minnesota section of the classification (Figure 3).

RESULTS

A pixel-wise accuracy assessment of the 2007 MODIS NDVI classification was performed using 2005-2006 NAIP DOQs as reference (Figure 3). A total of 181 random samples were selected from the Minnesota section of the Omernik ecoregion, equally divided by 'pure' and 'edge' pixel status. Overall accuracy inclusive of both 'edge' and 'pure' reference pixels yielded a value of 59.1% when compared to the assessments using only 'edge' pixels (52.1%) and only 'pure' pixels (68.8%). Two of the three error matrices yielded Kappa statistics indicating poor agreement between the reference data and the classification ('pure' and 'edge' = 0.30; 'edge' = 0.20), whereas moderate agreement was found between the 'pure' reference data and the classification (0.43). There were no significant differences when comparing pair-wise for all combinations of all three matrices when testing at a 95% confidence level. A number of observations can be made after taking a cursory look at the confusion between the classes. User's accuracy indicates confusion between coniferous and deciduous vegetation within all three error matrices (30-54%). This can be attributed to the dominance of stagnant black spruce and cedar within this region. A possible explanation could be that deciduous understory vegetation has spectral dominance of the coniferous overstory counterpart. To correct this issue, a leaf-off image (e.g. Landsat 7) will be used in the next iteration to utilize the infra-red component within band-4. Used in conjunction with the NAIP DOQs, these spectral issues should become evident. In general, the inclusion of 'pure' reference pixels only does provide higher accuracy values than assessments done using 'edge' pixels also. The 'pure' only reference pixel prerequisite is difficult to fulfill in a highly heterogeneous landscape as is found within this region.

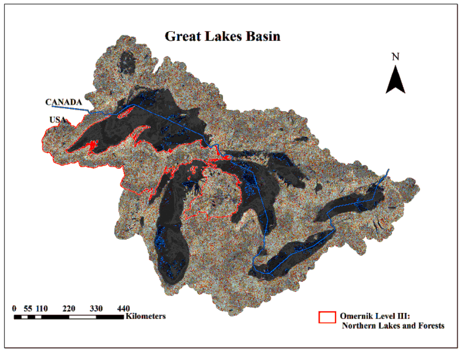

Fig. 1. Great Lakes Basin Landsat 7 ETM+ mosaic with Omernik level III ecoregion

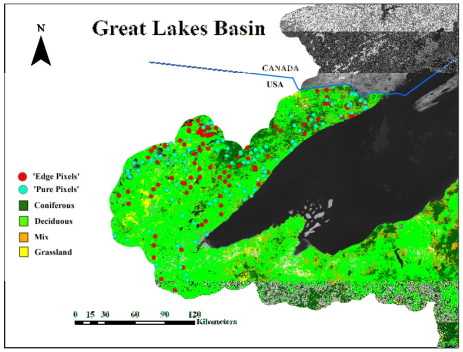

Fig. 2. Omernik level III Classified Map (Minnesota) with reference points

PURE+EDGE

Classification	M	C	D	G	% Correct	% Comission
Mix (M)	1	3	7	1	8.3	91.7
Coniferous (C)	4	34	36	9	41.0	59.0
Deciduous (D)	7	7	72	0	83.7	16.3
Grassland (G)	0	0	0	0	NA	NA
% Correct	8.3	77.3	62.6	0	**59.1**	Kappa = 0.29
% Omission	91.7	22.7	37.4	100		

EDGE

Classification	M	C	D	G	% Correct	% Comission
Mix (M)	0	2	7	1	0	100
Coniferous (C)	3	13	22	5	30.2	69.8
Deciduous (D)	3	3	37	0	86.0	14.0
Grassland (G)	0	0	0	0	NA	NA
% Correct	0	72.2	56.1	0	**52.1**	Kappa = 0.20
% Omission	100	27.8	43.9	100		

PURE

Classification	M	C	D	G	% Correct	% Comission
Mix (M)	0	0	0	0	NA	NA
Coniferous (C)	1	20	12	4	54.1	45.9
Deciduous (D)	4	4	35	0	81.4	18.6
Grassland (G)	0	0	0	0	NA	NA
% Correct	0	83.3	74.5	0	**68.8**	Kappa = 0.43
% Omission	100	16.7	25.5	100		

Fig. 3. Error matrices for three reference pixel types: PURE+EDGE, PURE, EDGE