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

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***Abstract*— A number of articles have investigated the impact of sampling design on remotely sensed landcover 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 landcover 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 (center pixel within a 3 x 3 window) and (2) Isolated independent pixel sampling (i.e. 'edge pixels'). MODIS spectral characteristics typically 'bleed' from adjacent pixels, causing pure 'edge pixels' to be suspect with respect to their homogeneity. 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.**

Keywords: MODIS, NDVI, accuracy

Note: Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy.

I. Introduction

Studies of accuracy assessments of landcover derived from high resolution imagery (e.g. Landsat ETM$^+$ 30 m resolution) 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 (Plourde and Congalton, 2003; Gong and Howarth, 1990). 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, landcover generated from the Moderate Resolution Imaging Spectroradiometer (MODIS) 250 m normalized difference vegetation index (NDVI) time-series data is 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. Corrective measures have been developed by the MODIS Science Team to offset the variation attributed to sun-sensor geometry and the atmosphere. With respect to sun-sensor geometric issues, 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). MODIS swath width is approximately 2340 km where nadir pixel resolution approaches 250 m cell size. However, off-nadir the observation angle approaches 55 degrees 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.

Beyond the initial gridding procedure, MODIS NDVI time-series compilation also employs a compositing procedure to produce a single representative dataset. The MODIS NDVI dataset is composited over a 16-day period where the maximum NDVI observation is chosen within the 16-date period from an image that is closest to the near-nadir viewing angle in order to minimize atmospheric contamination. Atmospheric attenuation (i.e. scattering and water vapor absorption) 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. With atmospheric effects reduced however, 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. Figure 1 (by permission from Huete et al., 1999) details the sun-sensor geometry and bi-directional reflectance effects that impact the NDVI data quality retrieved from the MODIS sensor. Data quality is reduced at the swath edges.

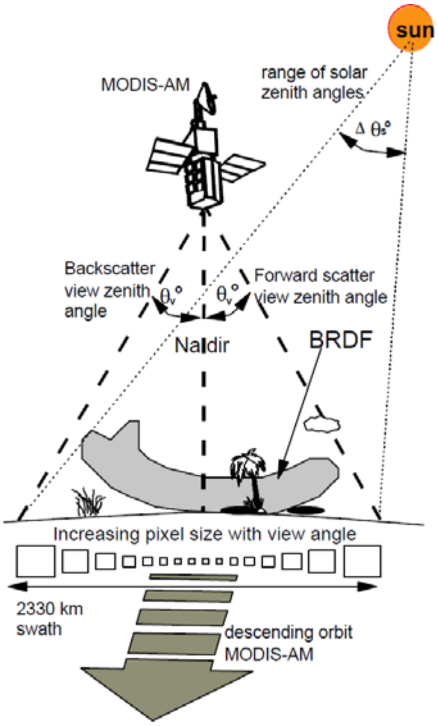

Figure 1. Illustration of MODIS data acquisition on the EOS-AM platform (not to scale). The bidirectional reflectance distribution function (BRDF) changes with view and sun geometry. Notice the shadow caused by clouds and canopy. MODIS pixel dimensions, cross-track and along-track, change with scan angles: 0° - 250 x 250 m; 15° - 270 x 260 m; 30° - 350 x 285 m; 45° - 610 x 380 m (computed for the fine resolution red and NIR detectors; 250 m at nadir on the ground). (Courtesy of Huete et al., 1999)

II. Study Area

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 2). The Northern Lakes and Forests Ecoregion is characterized by moist low boreal and subhumid transitional low boreal ecoclimates and consists of mixed conifer and deciduous forests and wetlands. This ecoregion experiences warm summers and cold winters with mean annual temperature ranges of 1.5°C. Mean summer temperature ranges from 14°C to 15.5°C with mean winter temperature averaging -13°C. Mean annual precipitation ranges from 500 mm in the west to 700-800 mm in the east.

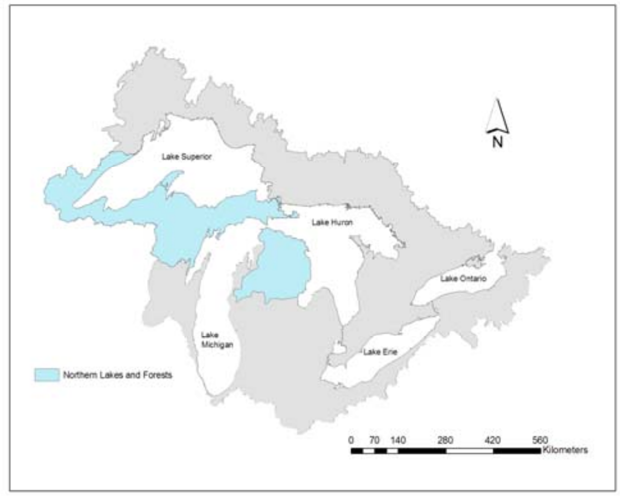

Figure 2. Omernik Level III Ecoregion (Northern Lakes and Forests)

III. Methods

A. Data Acquisition and Preprocessing

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 Alber's Equal Area Conic projection (nearest neighbor sampling routine). A 250 m x 250 m grid multilayer image stack was then generated. In order to provide a high quality uninterrupted data stream, data with non-high quality NDVI data values were identified from internal quality control data flags and removed. The raw NDVI data were then filtered using a discrete Fourier transformation to first decompose the data into low frequency components of signal and high frequency components of noise. A discrete Fourier transformation was then used to transform the removed NDVI values into the frequency domain where the signal was separated from the noise. A non-linear deconvolution approach (Roberts et al., 1987) was implemented to estimate data points from the frequency domain signal spectrum. This process described by Lunetta et al. (2006) provides a "clean" NDVI temporal profile.

B. 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 landcover class. Therefore, in order to focus solely on natural vegetation, the water, agriculture, and urban landcover classes 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. In an earlier study, MODIS NDVI time-series classification techniques were unable to separate the coniferous and deciduous landcover class from woody wetland areas, therefore wetlands in this study were classified as either coniferous, deciduous, or mixed (Knight et al., 2006). 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. 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).

C. *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 landcover type and position within homogeneous areas. Grid cells centered within a 3 x 3 window labeled as 100 percent one landcover type were noted as to those grid cells isolated from similar landcover 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.

IV. Results

Disregarding sampling placement initial accuracy analysis indicates that only 78.5% of the sample pixels were labeled correctly (Figure 3). The most problematic forest landcover class was 'mixed forest' where 27.4% of the reference pixels were correctly classified. Further results were provided at the Accuracy 2010 poster session.

Classification

Reference	"43" 1	"42" 2	"41" 3	"71" 4	"21" 5	"31" 6	Total	%Correct
"43" 1	20	29	22	2	0	0	73	27.4
"42" 2	6	121	6	2	0	0	135	89.6
"41" 3	27	26	295	1	0	0	349	84.5
"71" 4	0	0	1	3	0	0	4	NA
"21" 5	0	0	0	0	5	0	5	NA
"31" 6	0	0	0	0	0	2	2	NA
Total	53	176	324	8	5	2	**568**	
%Correct	NA	68.8	91.0	37.5	NA	NA		

%Correct Overall = 78.5

Figure 3. Overall accuracy assessment integrating both pure-pixel and edge-pixel sampling for six landcover types: 21 – Urban, 31 – Bare, 41 – Deciduous, 42 – Coniferous, 43 – Mixed, 71 – Grasslands.

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References

Congalton, R.G., and K. Green, 1999. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices* (137 p), Boca Raton, FL: Lewis Publishers

Gong, P. and Howarth, P.J. (1990). An assessment of some factors influencing multispectral land-cover classification. *Photogrammetric Engineering and Remote Sensing*, Volume 56, Number 5, 597-603.

Huete A.R., Justice, C., VanLeeuwen, W. (1999) Modis vegetation index (MOD 13) algorithm theoretical basis document. Internet: http://modis.gsfc.nasa.gov/data/atbd/atbd_mod13.pdf (2010/04/15)

Knight, J.F., Lunetta, R.S., Ediriwickrema, J., and Khorram, S. (2006). Regional scale land cover characterization using MODIS-NDVI 250 m multi-temporal imagery: A phenology-based approach. *GIScience & Remote Sensing*, Volume 43, Number 1, 1548-1603.

Plourde, L. and Congalton, R.G. (2003). Sampling method and sample placement: How do they affect the accuracy of remotely sensed maps? *Photogrammetric Engineering and Remote Sensing*. Volume 69, Number 3, 289-297

Roberts, D.H., Lehar, J., and Dreher, J.W. (1987). Time series analysis with clean I. derivation of a spectrum. *The Astronomical Journal*. Volume 93, Number 4, 968-989.

Shao, Y., Lunetta, R.S., Ediriwickrema, J., and Iiames, J. (2010). Mapping cropland and major crop types across the Great Lakes Basin using MODIS-NDVI data. *Photogrammetric Engineering and Remote Sensing*, Volume 75, Number 1, 73-84.

Wolfe, R.E., Roy, D.P., and Vermote, E. (1998). MODIS land data storage, gridding and compositing methodology: Level 2 grid. *IEEE Transactions on Geoscience and Remote Sensing*, Volume 36, Number 4, 1324-1338.