ON EXCHANGEABILITY OF SPECTRAL MEASUREMENTS OBTAINED FROM MULTI-PLATFORM SATELLITE SENSORS—CASE STUDY FOR MONGOLIAN STEPPE

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ABSTRACT: Spectral measurements collected in the field are often being scaled up to its counterparts from satellite sensors with little regard for exchangeability. Common assumption being that plot-scale (<2-3meters) spectral measurements and its derivatives—such as ratios or vegetation indices, can readily be scaled to the pixel-based spectral measurements, like Landsat grids (30m) or MODIS grids (250m). However, even after careful geo-registration and atmospheric correction efforts, the exchangeability may not always be automatically guaranteed. The objective of this study is to evaluate the exchangeability of the surface reflectance values among high-resolution GeoEye-1, medium-resolution Landsat/TM, and coarse-resolution MODIS image data over a relatively homogenous steppe in Mongolia (Baganuur; 14 km × 15 km; 47° 41' N, 108° 17' E). We co-registered the images to a subpixel accuracy and applied the FLAASH atmospheric correction to retrieve the surface reflectance values. Plot-scale GeoEye-1 reflectance reasonably agreed with Landsat/TM grids (R=0.71—0.74 for red and near-infrared bands; n=193,830; p<0.0001) while the agreement suffered with MODIS grids (R=0.36—0.61 for red and near-infrared bands; n=2,754; p<0.0001) particularly in terms of GeoEye-1 reflectance values constantly higher than those of MODIS grids by around 0.1. When compared for NDVI, that is band ratio in nature, GeoEye-1 NDVI proved comparable with both Landsat/TM NDVI and MODIS NDVI (R=0.81; p<0.0001 and R=0.65; p<0.0001, respectively). Results indicated that the users should be aware of the potential bias when using spectral measurements from multi-platform satellite sensors particularly with different spatial resolutions. Much caution is required when scaling plot-scale measurements to coarse-resolution MODIS spectral measurements. In our test case in Mongolian steppe, the exchangeability of NDVI values, a normalized transformation of the NIR to red reflectance ratio, was better compared to that of individual surface reflectance values.

1. INTRODUCTION

Many research work exists that attempts to directly or indirectly relate the spectral measurements acquired from space to some kind of bio-physical parameters like carbon stock or biomass on the ground (Eckert, 2012; Karnieli, *et al*., 2011). In doing so, spectral measurements collected in the field at the plot-scale are often scaled up to a variety of spatial resolutions of different satellite sensors. However, in-depth investigations or discussions in the exchangeability issues among data with different spatial resolutions are somewhat limited (Baccini, *et al*., 2007; Wilson, *et al*., 2010). Even for the image data acquired over a semi-arid landscape with a relatively homogeneous spectral variability and texture, some case studies have reported a potential issue in blindly taking the mutual exchangeability among spectral data from multiple sensors for granted (Theau, *et al*., 2010). At the same time, the use of satellite remote sensors for characterizing such semi-arid landscapes can give us an advantage in monitoring large areas and capturing the spatial variability of the land surface where dense ground monitoring network is not likely available. It is, then, very important to shed a light on case studies that examine the correspondence among the spectral data of the same target on the ground with different spatial resolutions. The objective of this study is to evaluate the exchangeability of the surface reflectance values and its derivative among high-resolution, medium-resolution, and coarse-resolution satellite data over a relatively homogenous Mongolian steppe.

2. STUDY AREA

Our study area is located just south of Baganuur (14 km × 15 km; 47° 41' N, 108° 17' E), a satellite district of Ulaanbaatar. It is located approximately 140 km east of the Mongolian capital city and consists of a typical steppe and an area of open-pit brown coal mine (Figure 1, Figure 2).

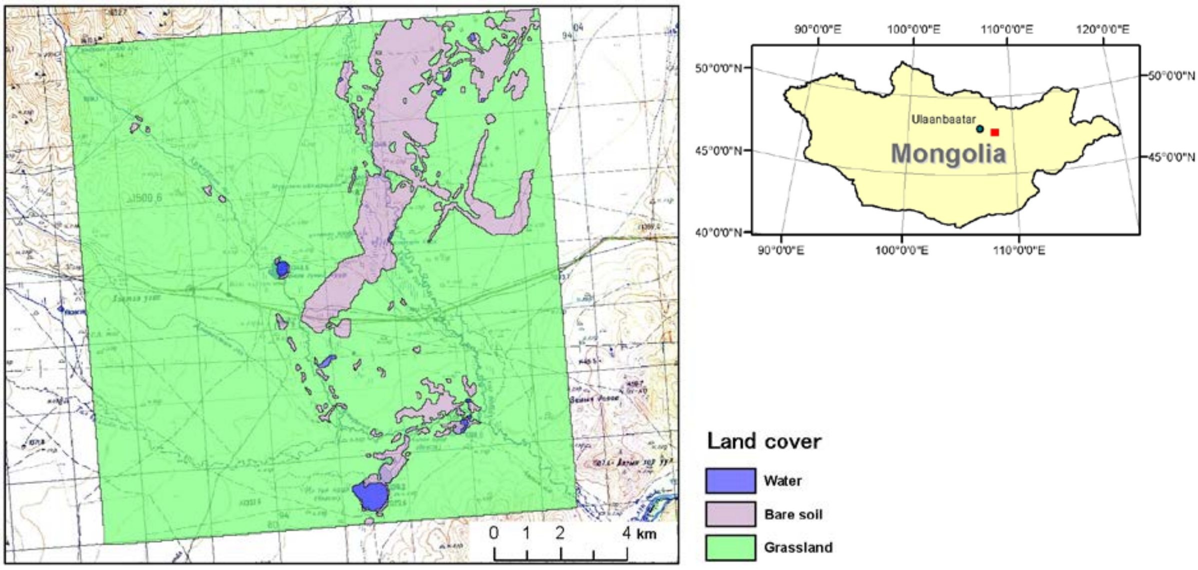

Figure 1: Location and land cover of the study area.

Figure 2: General landscape of the study area.

3. DATA AND METHODOLOGY

We used a high-resolution GeoEye-1 (multispectral; 2m), medium-resolution Landsat5/TM (multispectral; 30m), and coarse-resolution MODIS (red and near-infrared; 250m) image data acquired within a 10-day interval (Table 1). Landsat data were first co-registered to GeoEye-1 data, and subsequently, MODIS data were co-registered to Landsat data with approximately half-a-pixel root-mean-square error (RMSE). All image data were clipped to the area extracted from the original GeoEye-1 scene occupying approximately 210 km^2. Both GeoEye-1 and Landsat data were corrected for atmospheric attenuation and converted to the surface spectral reflectance using Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) atmospheric correction program available with Exelis VIS's ENVI 5.0 software package. Only MODIS data (Surface reflectance daily L2G global 250m: MOD09GQ) came pre-processed with atmospheric correction and was provided as an estimate of the surface spectral reflectance as it would be measured at ground level.

Table1. Specifications of the data used in this study.

Satellite sensor	Data acquisition date	Sensor altitude (km)	Ground resolution (m)
GeoEye-1	2010/6/13	681	2
Landsat5/TM	2010/6/22	705	30
MODIS	2010/6/13	705	250

In order to accommodate the locational misregistration, a square buffer with about half-a-pixel distance was created around each coarser pixel coverage to calculate the counterpart spectral data from a finer pixel image (schematic diagram shown in Figure 3). We compared the corresponding red reflectance (RED), near-infrared reflectance (NIR) between GeoEye-1 and Landsat; GeoEye-1 and MODIS data. We also calculated a commonly used normalized difference vegetation index (NDVI) , which is a transformation of a spectral ratio (NIR/RED) for all three image data, and compared them in the same manner.

We used the ENVI software for most image processing operations and ESRI's ArcGIS 10.2.1 for Desktop for vector analyses, geospatial analyses and visualization.

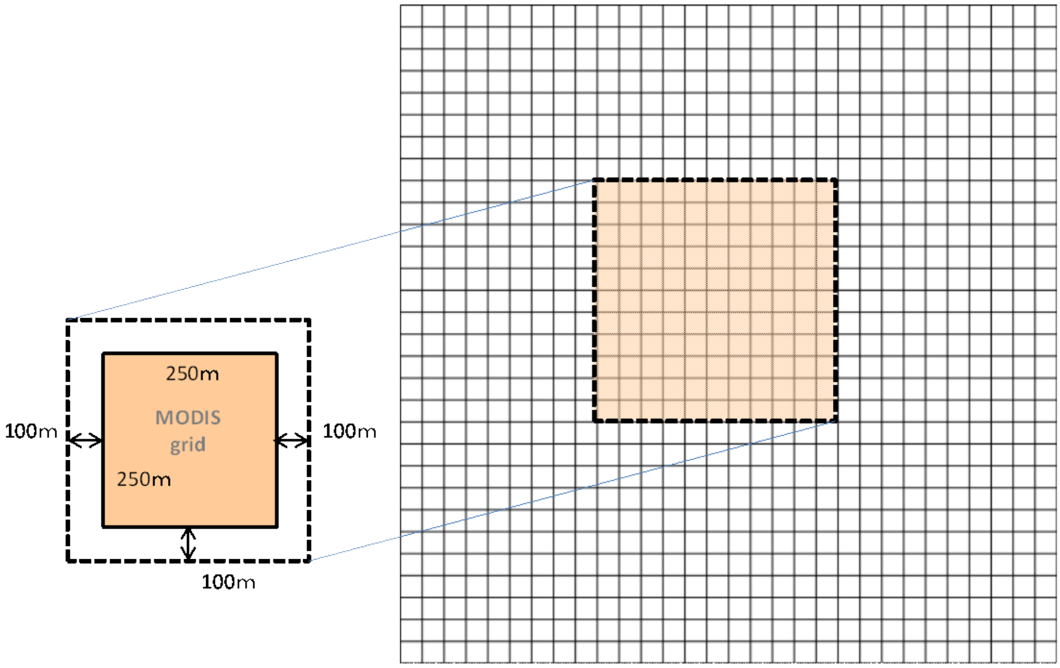

Figure 3: Schematic diagram of creating a buffer around a coarser pixel coverage to summarize the spectral data from the finer resolution image data.

4. RESULTS AND DISCUSSION

Figure 4 shows the difference in appearance among satellite images (RED) with varying spatial resolutions. Since the image acquisition dates were close together, overall tonal patterns particularly between GeyEye-1 and Landsat data looked very similar. However, even by visual inspection, we noticed some artifacts in the coarse-resolution MODIS data, most of which corresponded with relatively poor QA (quality assurance) coded pixels.

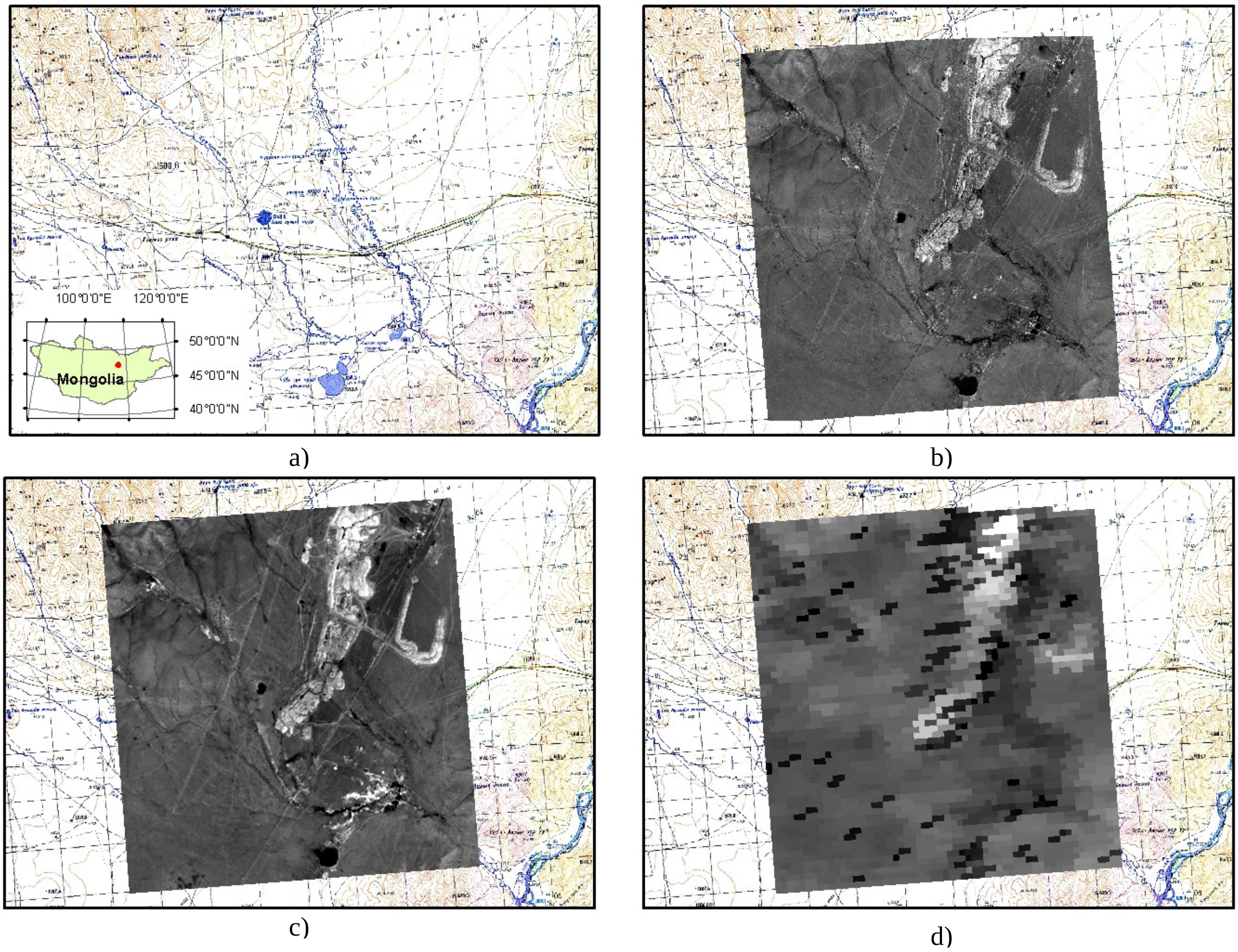

Figure 4: Satellite images (RED) of the study area captured by different sensors.
a) topographic map; b) GeoEye-1; c) Landsat/TM; d) MODIS

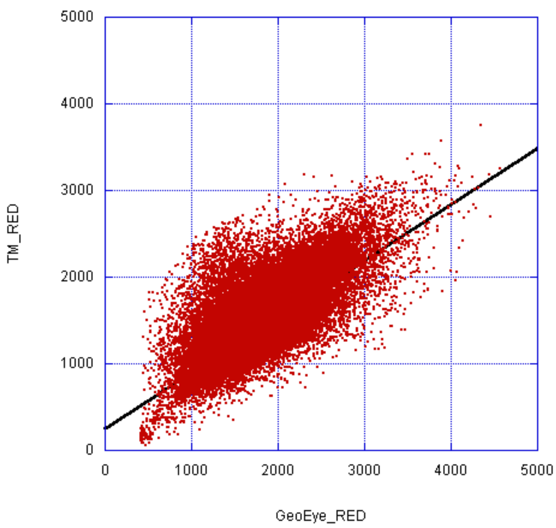

Figure 5: Scatter plot of GeoEye-1 RED and Landsat/TM RED

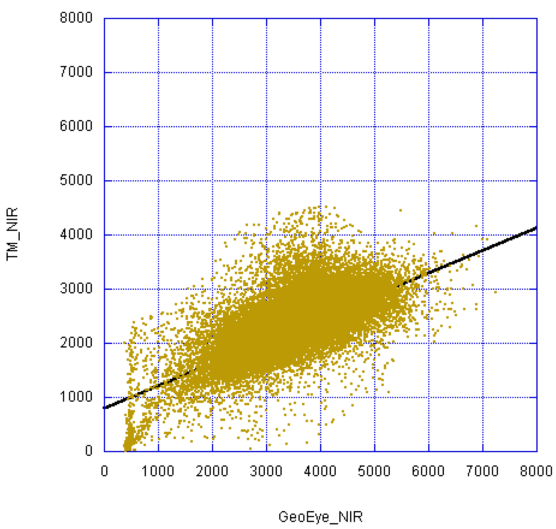

Figure 6: Scatter plot of GeoEye-1 NIR and Landsat/TM NIR

Figures 5 and 6 show the scatter plots of corresponding RED and NIR surface reflectance (scaled by 10,000) values for GeoEye-1 and Landsat/TM data. Although GeoEye-1 values were constantly higher than those of corresponding Landsat/TM by 0.05—0.1, overall R were 0.71—0.74, respectively and reasonably agreed well.

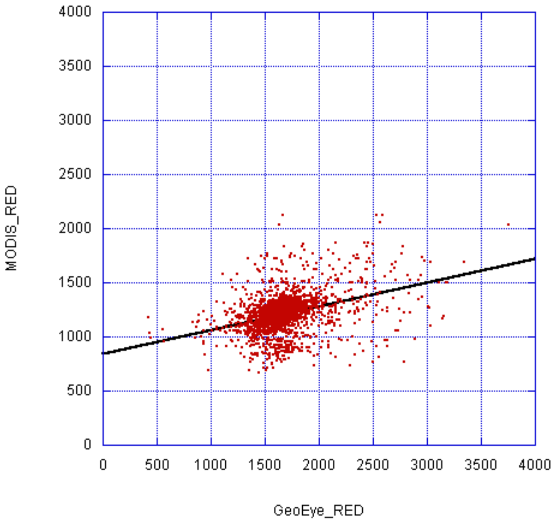

Figure 7: Scatter plot of GeoEye-1 RED and MODIS RED

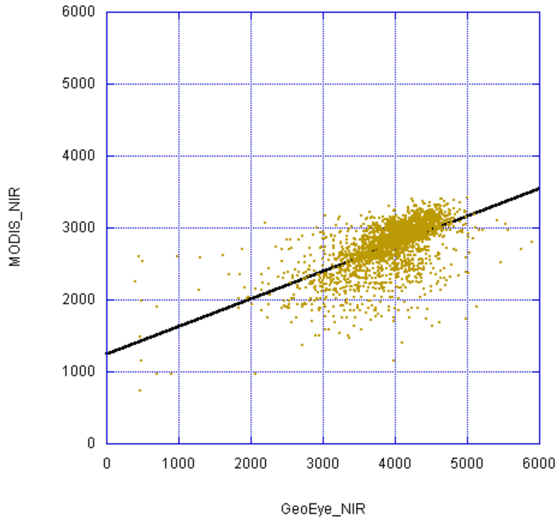

Figure 8: Scatter plot of GeoEye-1 NIR and MODIS NIR

Spectral reflectance values between GeoEye-1 and MODIS (RED and NIR wavelength regions) did not agree very well (R=0.36—0.61) while GeoEye-1 RED and NIR values constantly higher than MODIS counterparts by around 0.1 (Figures 7 and 8). The discrepancy could come from the different algorithm of the atmospheric correction but more detailed assessment will be needed to draw a definitive conclusion.

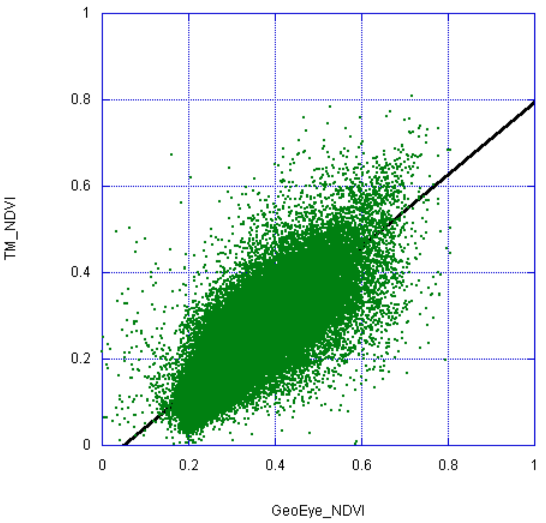

Figure 9: Scatter plot of GeoEye-1 NDVI and Landsat NDVI

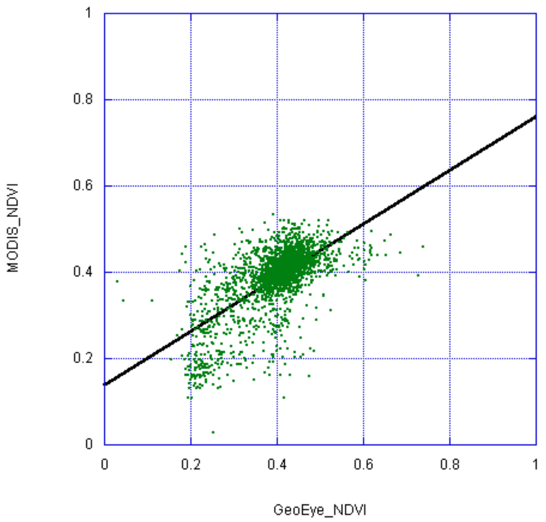

Figure 10: Scatter plot of GeoEye-1 NDVI and MODIS NDVI

When compared for NDVI values, a normalized transformation of the NIR to RED ratio, both combinations (GeoEye-1 and Landsat; GeoEye-1 and MODIS) yielded good agreement (R=0.81; p<0.0001 and R=0.65; p<0.0001, respectively) (Figures 9 and 10). Since NDVI is band ratio in nature, we believe the effect of different atmospheric correction on each spectral band were somehow canceled out and thus resulted in a reasonable agreement.

5. CONCLUSIONS

Results from our test case in Mongolian steppe indicated that the plot-scale spectral measurements should not automatically be scaled up to a coarser grids. The exchangeability among spectral measurements with different spatial resolutions needs to be validated whenever possible after appropriate geo-registration and atmospheric correction. Locational error factor should be taken into account when corresponding spectral measurements are spatially summarized. Even after the state-of-the-art atmospheric correction efforts, surface reflectance values between overly different pixel sizes are not likely to agree well. However, vegetation indices like NDVI appeared comparable with different spatial resolutions. It is still important that the users should be aware of the potential bias using spectral data from multi-platform satellite sensors with different spatial resolutions.

ACKNOWLEGMENTS

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