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Normalization of NDVI from Different Sensor System using MODIS Products as Reference

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Abstract. Medium Resolution NDVI(Normalized Difference Vegetation Index) from different sensor systems such as Landsat, SPOT, ASTER, CBERS and HJ-1A/1B satellites provide detailed spatial information for studies of ecosystems, vegetation biophysics, and land cover. Limitation of sensor designs, cloud contamination, and sensor failure highlighted the need to normalize and integrate NDVI from multiple sensor system in order to create a consistent, long-term NDVI data set. In this paper, we used a reference-based method for NDVI normalization. And present an application of this approach which covert Landsat ETM+ NDVI calculated by digital number ($NDVI_{DN}$) to NDVI calculated by surface reflectance ($NDVI_{SR}$) using MODIS products as reference, and different cluster was treated differently. Result shows that this approach can produce NDVI with highly agreement to NDVI calculated by surface reflectance from physical approaches based on 6S (Second Simulation of the satellite Signal in the Solar Spectrum). Although some variability exists, the cluster specified reference based approach shows considerable potential for NDVI normalization. Therefore, NDVI products in MODIS era from different sources can be combined for time-series analysis, biophysical parameter retrievals, and other downstream analysis.

1. Introduction

Detailed information about vegetation is important for a wild range of application from studies of ecosystem, vegetation biophysics on regional and global scales. The Normalized Difference Vegetation Index (NDVI), calculated from the spectral reflectance measured in the visible and infrared bands of a satellite sensor, provides an indication of photosynthetically active vegetation [1].Medium Resolution NDVI from different sensor systems such as Landsat TM/ETM+, SPOT/HRG, ASTER, CBERS and HJ-1A/1B satellites provide detailed spatial information. Maintaining a continuous data set is a critical need for the Earth science community [2].

However, trade-offs in sensor designs, cloud contamination or duty cycle limitation, sensor failure and so on highlighted the need for methods to integrate NDVI from multiple sensor system in order to create a consistent, long-term NDVI data set[3]. But Integration of NDVI from different sensors is complicated, for various factors are known to affect the consistency and continuous of long-term NDVI data set [4-6]. Spatiotemporal variations in NDVI observed over a certain area do not

necessarily represent changes in vegetation, but may depend on the circumstances of observation or result from artifacts introduced during data processing [7].

Theoretically surface reflectance is a physical measurement not affected by instrument calibration issues or atmospheric effects. It is pointed out that using equivalent surface reflectance data in computation of the vegetation index (VI) eliminated many of the errors and provides a sound basis for the comparison of indices measured over time or by multiple sensors [5]. Thus $NDVI_{SR}$ (NDVI calculated by surface reflectance) could be the basis for NDVI integration.

$NDVI_{SR}$ can be accomplished using surface reflectance derived from physical radiative transfer model or empirical approach [7], or relative radiometric correction approaches [8]. However, even if we could get the atmospherically corrected surface reflectance, The NDVI from different sensors may still not be comparable due to differences in sensor bandwidths or illumination and sun-viewer geometries.

One approach to make a consistent data set from multiple sensors is to normalize measurements form those sensor using a consistent data set as reference. This idea has been used for normalizing reflectance data from different sensor systems [9, 10].

Focus of this paper is applying and analyzing the reference-based approach for converting NDVI to a standard $NDVI_{SR}$ product. MODIS product which is consistent and globally available is used as the reference. The result of applying this approach on Landsat ETM+ $NDVI_{DN}$ is presented. And the performance of the reference-based approach is evaluated and analyzed.

2. Method

The basis of the method is that the linear models built using homogeneous pixels are scalable in different spatial resolution. Linear model is used to convert NDVI calculated from digital number or other to $NDVI_{SR}$, relationships is built on the MODIS data and the aggregated medium resolution data, and then is applied to medium resolution data to produce $NDVI_{SR}$ at the medium resolution. The relationship is built on MODIS resolution using MODIS products as reference based on the homogeneous pixels, and different models are established for different land cover types for NDVI.

The total workflow can be disparate to four steps:

- The medium resolution data should be registered, reprojected and resampled to the MODIS resolution. Cloud mask was applied to both medium resolution NDVI and the reference MODIS NDVI data. And pixels with bad quality of the MODIS NDVI are also masked.
- An unsupervised classification is applied to the medium resolution NDVI. And based on the classification result, the majority spectral cluster type of each MODIS pixel is computed and also used as criteria to determine homogeneity of MODIS pixel.
- Relationship between medium resolution NDVI and MODIS NDVI for each cluster are built using cloud-free coarse-resolution homogeneous pixels. The homogeneous pixel at MODIS resolution for each cluster type is determined by the predefined percentage of majority cluster.
- These relations are then applied to the original medium resolution NDVI and produce $NDVI_{SR}$ for medium resolution. For small clusters lack of enough good homogeneous samples, the global relation based on the samples of all cluster types will be used alternatively.

Linear from is used to relate MODIS NDVI and medium resolution NDVI for each cluster. It can be expressed as:

$$y = a * x + b \qquad (1)$$

Where y represents MODIS NDVI products and x represents the aggregated NDVI from the medium resolution NDVI data, a and b are the intercept and slope.

For least squares estimators are vulnerable to the outliers. Even when data contains only one bad data, least-squares estimates may be completely perturbed [11]. M-estimation is adopted to make a robust fit which can identify and remove outlier so as to weaken their effect on parameter estimates and to improve the accuracy of estimated parameter.

Formula (1) can be expressed as

$$Y = BX \qquad (2)$$

Using algorithm based on M-estimator, we get result through an iterative solution of formula (4):

$$B^{(k)} = (X^T w^{(k-1)} X)^{-1} X^T w^{(k-1)} Y \qquad (3)$$

Here w represent the weight of each point. Huber function is chose to determine the associated weights for each point.

The MODIS land products provide information at spatial resolution of 250, 500 and 1000 meters covering the period since 2000. And the MODIS land products have been partially validated in "validated stage 1"[12]or "validated stage 2"[13], and pixel-based quality control information is associated with each product. As the MODIS data products consistent, and freely available, it is suitable to be reference for NDVI normalization.

The MODIS 16-days Normalized Difference Vegetation Index products (MOD13/MYD13), the NDVI calculated by MODIS daily surface reflectance products (MOD09/MYD09) can both be used as the reference in our work. The first one are provided every 16-days at 1km spatial resolution, computed from atmospherically corrected bi-directional surface reflectance that have been masked for water, clouds, heavy aerosols, and cloud shadows. And Version-5 MODIS/Terra vegetation indices products are validated stage2.The second choice is provided every day and provides an estimate of the surface spectral reflectance as it would be measured at ground level in the absence of atmospheric scattering or absorption.

3. Result and Discussion

A scene of Landsat 7-ETM+ data covering the Wuhan area in China (WRS-2 path 123 and row 39) acquired on July 22, 2001 was chose for experiment. Since this Landsat scene is located in the MODIS tile boundary. Just part of the ETM+ scene was used in this experiment (Figure 1.a). Figure 1.b shows its $NDVI_{DN}$. The terra/MODIS crosses the equator at about 10:30Am local solar time. Roughly 30 minutes later than Landsat-7. And the viewing and solar geometries are close to those of the corresponding Landsat acquisition. This allows us to directly use MODIS NDVI (Figure 1.c) calculated from MODIS daily surface reflectance as a reference for Landsat ETM+ NDVI normalization.

Fig.1d shows the result, the normalized $NDVI_{SR}$ using the empirical approach follow the workflow introduced in 2.1. As the result was produced using MODIS products as reference, we identified it as "$MODIS\_like\_NDVI_{SR}$".

For evaluation, $NDVI_{SR}$ calculated from surface reflectance derived from physical approach was achieved (Figure.1.e). LEDAPS, which is developed to create a Landsat-based surface reflectance adopting "6S" approach for atmospheric correction, was used to get the surface reflectance. The MODIS-based atmospheric correction method was found to have slightly better accuracy than the LEDAPS method. The LEDAPS approach has accuracy that only slightly worse than MODIS-based atmospheric correction method[14].
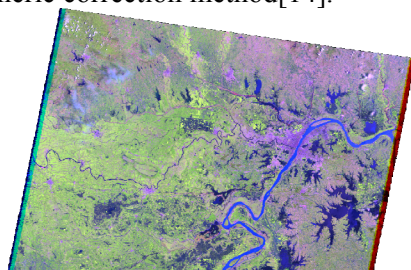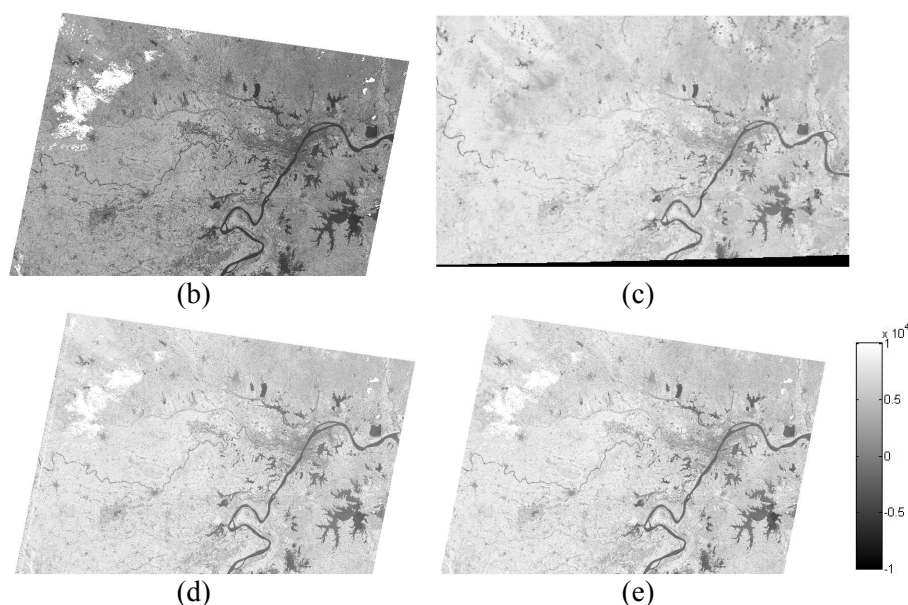

(a)

Figure 1. False-color composite ETM+ image (a) and ETM+ NDVI$_{DN}$ (b) and MODIS NDVI$_{SR}$ (c) and ETM+ MODIS_like_NDVI$_{SR}$ (d) and ETM+ NDVI$_{SR}$(e) for Wuhan area (Landsat WRS-2 path 123 and row 39). Black areas in (c) and white area in (b) (d) (e) represents cloud, missing or poor quality data.

Figure 1.d and Figure 1.e shows very similar NDVI. Figure 2.a shows the histogram of NDVI$_{DN}$ and MODIS_like_NDVI$_{SR}$, obvious difference can be seen between them, this implies that such an approach change the value significantly. Figure 2.b shows the histogram of MODIS_like_NDVI$_{SR}$ and NDVI$_{SR}$, their position and shape are approximately same as the other. And the statistics of the two NDVI listed in table 1 also illustrate the similarity between them.
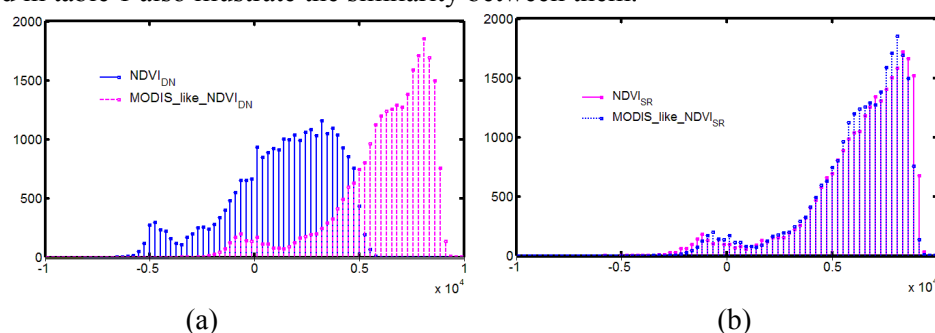

Figure 2. Histogram of NDVI$_{DN}$ and NDVI MODIS_like_NDVI$_{SR}$ (a) and histogram of NDVI$_{SR}$ and NDVI MODIS_like_NDVI$_{SR}$ (b) respectively (*10000)

Table 1. Statistic value -maximum (max) and minimum (min) and mean and median data of NDVI$_{SR}$ and MODIS_like_NDVI$_{SR}$

	max	min	mean	median
NDVI$_{SR}$	0.9505	-0.5895	0.63004	0.6895
MODIS_like_NDVI$_{SR}$	1.0384	-0.3777	0.61354	0.6476

Moreover, a strong linear relation between the MODIS_like_NDVI$_{SR}$ and NDVI$_{SR}$ can be seen from the scatter plots in Figure 3.a, the scatter is tightly around the 1 to 1 line. And the correlation coefficient (R) is high as 0.9914 (table 2), while the average relative error (ARE) is low to 0.09 and mean square error (MSE) only 0.00126. By comparison, there is nonlinear relation between NDVI$_{DN}$ and NDVI$_{SR}$, which can be found from Figure 3.b. Different color in Figure 3.b stands for different

cluster. However, the relationship of samples between $NDVI_{DN}$ and $NDVI_{SR}$ within one cluster seem to can be treated as linear approximately (Figure 3.b), and we think maybe it is the reason that why this cluster specified reference based method works well for NDVI normalization. However, the relationship deviates from the exacted 1 to 1 line. This implies that the $MODIS\_like\_NDVI_{SR}$ from the empirical approach may not precisely duplicate the true $NDVI_{SR}$, may be due to the instinct difference in sensor characteristic between MODIS and ETM+.
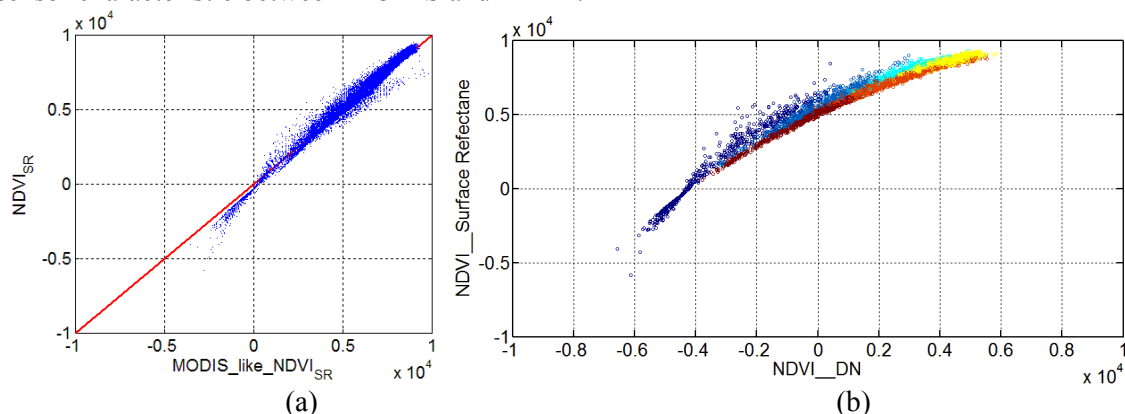

Figure 3. Scattering plots of $MODIS\_like\_NDVI_{SR}$ and $NDVI_{SR}$ (a) and Scattering plots of $NDVI_{DN}$ and $NDVI_{SR}$ (b) respectively (*10000)

Table 2. Correlation coefficient (R) and Mean square error (MSE) and Mean absolute difference (MAD) and mean difference (MD) and average relative error (ARE) among $NDVI_{SR}$ and $MODIS\_like\_NDVI_{SR}$

R	MSE	MAD	MD	ARE
0.9914	0.00126	0.02716	-0.01113	0.09357

4. Conclusion

For medium spatial resolution NDVI are extremely useful for local and regional remote sensing applications, integrating NDVI from difference sensors can guarantee the consistency and continuity of the medium resolution NDVI data set, reduce both of its spatial and temporal gap. Application of the reference-based approach shows considerable potential for combining data from different sensors using one "standard" NDVI data as reference data, such as the consistent and continuous MODIS products.

The cluster specified linear model performs well for the nonlinear relation between $NDVI_{DN}$ and $NDVI_{SR}$. And the $MODIS\_like\_NDVI_{SR}$ of the experiment shows similar accuracy with $NDVI_{SR}$ derived from physically-based atmospheric corrected reflectance. However, difference between the two may due to the intrinsic difference between MODIS products and Landsat ETM+ products, and the application will limited by the reference data. However, further experiment on other sensors, among different sensors, need to be taken to evaluate its applicability and performance for NDVI normalization. Deeply work is needed to perfect this reference-based method.

However, there are factors influencing the effect of this method and need to be pay attention to. Such as the geo-registration accuracy, difference in illumination and viewing geometry, difference of the sensor characteristic and so on.

Whatever, such a reference-based approach provides a way to normalize NDVI from different sensors to one standard and thus allows continuous time-series analysis. The idea that using reference data to normalize and thus integrate NDVI is worth tying.

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