MONOTONICITY OF AREA AVERAGED NDVI AS A FUNCTION OF SPATIAL RESOLUTION BASED ON A VARIABLE ENDMEMBER LINEAR MIXTURE MODEL

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1. BACKGROUND
Synergistic use of remotely sensed data with different spatial resolutions is unavoidable in some monitoring and calibration activities. For example, a series of satellite sensors, such as NOAA-AVHRR, Terra/Aqua-MODIS, and the future NPOESS VI-IRS sensor, are required when monitoring activities span over several decades, e.g., investigations of climate changes in context of global warming. Even for environmental monitoring in relatively short period of time, simultaneous use of multiple sensors would provide more chances of observation, which results in reduction of monitoring uncertainties. Planning overlapping period of two consecutive satellite missions is a standard strategy to cross-calibrate old and new sensors. All these activities, however, are influenced by scaling difference of observed radiance [1]. This scaling difference then induces gaps among retrieved parameters caused by nonlinearity of processing algorithms about spatial variables [2, 3, 4, 5]. This scaling issue, a fundamental issue encountered in various kinds of fusion process, needs to be resolved, where this paper tries to contribute.

Spatially averaged normalized difference vegetation index (NDVI) has been used repeatedly to extract key parameters for simulations of climate change. Differences in spatial averaging scheme during production processes, however, become a source of uncertainties in retrieved results [1, 3, 6, 7]. Therefore, the scaling issue of NDVI affects the accuracy of the global circulation models.

2. OBJECTIVE
The objective of this paper is to investigate the characteristics of spatially averaged NDVI value as a function of spatial resolution of satellite sensor represented by a number of pixel within a fixed area. Specifically, the paper focuses on the monotonicity about NDVI as a function of spatial resolution which was mentioned a few times by several researchers [4, 5]. However, up to this moment, no formal proof of such an important characteristic of averaged NDVI has been provided. Moreover, this fundamental characteristic has never been thoroughly discussed. This paper addresses these aspects of the problem from theoretical point of view based on a simple linear mixture model with a model of spatial resolution described below.

3. METHODS
Spatial resolution is modeled as a number of pixel, \( j \), within a fixed area illustrated by Fig. 1. Observed spectrum of pixel number \( k \) with \( j \)-th resolution, \( \rho_k \), and corresponding NDVI, \( V_{jk} \), are modeled by variable two-endmember linear mixture model where the endmembers consisted of vegetation \( \rho_v \) and non-vegetation surfaces, \( \rho_n \). Area averaged NDVI value observed at case of \( j \)-th resolution, \( \overline{V}_j \), is defined by \( \overline{V}_j = \frac{1}{j} \sum_{k=1}^{j} V_{jk} \), where \( V_{jk} \) is a function of two endmembers and fractions (or weights) of those endmembers. Then, monotonicity of \( \overline{V}_j \) is investigated as a difference of two consecutive \( \overline{V}_j \) about \( j \) defined by \( d = \overline{V}_m - \overline{V}_{(m+1)} \). The behavior of averaged NDVI value is analyzed as a function of endmember fraction and spectra.
Fig. 1. Illustration of resolution model and definitions of variable

4. RESULTS

We prove that a value of spatially averaged NDVI shifts monotonically as spatial resolution becomes higher when the pixel is composed of two types of object based on a linear mixture model regardless the fraction and distribution of the two objects.

The direction of changes (increasing or decreasing trend) can be determined from a ratio of the 1-norm of vegetation endmember spectrum, \(\|\rho_v\|_1\), to that of the non-vegetation endmember, \(\|\rho_n\|_1\). If the ratio, defined by \(\eta = \frac{\|\rho_v\|_1}{\|\rho_n\|_1}\), is less than or equal to one, the area averaged NDVI, \(\overline{V}_j\), is monotonic non-decreasing function. Contrary, the ratio (\(\eta\)) is greater or equal to one, the averaged NDVI, \(\overline{V}_j\), is monotonic non-increasing function. This finding is summarized by

\[
\overline{V}_j^{j+1} = \begin{cases} 
\geq \overline{V}_j^{j+1}, & \text{if } \|\rho_v\|_1 < \|\rho_n\|_1, \\
= \overline{V}_j^{j+1}, & \text{if } \|\rho_v\|_1 = \|\rho_n\|_1, \\
\leq \overline{V}_j^{j+1}, & \text{if } \|\rho_v\|_1 > \|\rho_n\|_1.
\end{cases}
\]  

5. IMPLICATIONS

The results indicate that the maximum and minimum value of averaged NDVI over a specific field occur when the resolution is the highest and the lowest (consisted with a single pixel over the target area).

This result implies the possibilities of estimating the range of averaged NDVI value with different scaling strategies. It enables us to discriminate errors due to the scaling discrepancies from the one induced by environmental changes. It also implies that in-situ spectral measurements can be used for an estimation of maximum or minimum values of averaged NDVI obtained from satellite data.

6. REFERENCES