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Precise Vegetation Index Mapping and Analysis Through AI-Based Atmospheric Correction of Sentinel-2 Satellite Imagery

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Abstract:

Between the Sun and the Earth's surface, and between the Earth's surface and satellites, an atmospheric layer exists. As electromagnetic waves pass through the atmosphere, interactions with atmospheric particles cause scattering, absorption, and refraction, leading to changes in both the direction and magnitude of energy transfer. Consequently, signals detected by sensors aboard satellites or aircraft inherently incorporate atmospheric influences, collectively referred to as atmospheric effects. These atmospheric effects act as significant obstacles in remote sensing, hindering the extraction of accurate surface information. Since the extent of atmospheric influence varies depending on atmospheric conditions and wavelength, atmospheric correction is an essential preprocessing step to remove or minimize errors and distortions in satellite imagery. The goal of atmospheric correction is to remove or compensate for atmospheric effects from Top of Atmosphere (TOA) reflectance observed by sensors, thereby retrieving accurate surface reflectance. With the expanding applications of Earth observation satellites for quantitative time-series analysis and the extraction of biophysical properties of surface materials, the need for atmospheric correction in terrestrial remote sensing is increasingly recognized. In agriculture and forestry, satellite-derived surface reflectance is utilized in diverse applications, such as forest species classification, crop growth monitoring, and vegetation index calculation. Even small differences in surface reflectance can significantly impact vegetation indices, and the importance of atmospheric correction is further magnified when using long-term time-series imagery(Lee (2019)). Chlorophyll in vegetation leaves exhibits distinct reflectance characteristics in the visible and near-infrared regions. By leveraging the difference in reflectance between these two wavelengths, the relative amount of chlorophyll within vegetation can be estimated. Among various vegetation indices, the Normalized Difference Vegetation Index (NDVI) is widely used for agricultural monitoring and assessing vegetation vigor. In this study, NDVI was utilized to create a vegetation index map specifically adapted to South Korea, and its results were analyzed. Beyond NDVI, this study evaluated the performance of the proposed atmospheric correction model on additional vegetation indices including GNDVI (Green Normalized Difference Vegetation Index) for chlorophyll-sensitive monitoring. Physical-based atmospheric correction methods provide high accuracy but are limited in real-time applications due to heavy computational demands. To address this issue, this study developed a machine learning-based atmospheric correction model that emulates physical models, focusing on improving both accuracy and computational efficiency. This research employed Random Forest (RF), an ensemble machine learning algorithm that constructs multiple decision trees and aggregates their predictions. RF was selected for its specific advantages of being excellent at learning nonlinear relationships between parameters, being robust against overfitting, and enabling effective multidimensional interpolation. The proposed AI-based model offers several distinct advantages over traditional approaches: (1) computational efficiency with processing times reduced from 90 minutes (linear interpolation) to 6 minutes while maintaining accuracy comparable to physics-based models, (2) enhanced handling of edge cases and discontinuous prediction patterns that traditional Look-up Table (LUT) interpolation (3) incorporation of physics-informed features that enable the model to better understand geometric and optical relationships, and (4) automated adaptation to varying atmospheric conditions without manual parameter tuning, making it suitable for operational applications. The proposed approach retains the efficiency of precomputed LUT methods while incorporating diverse atmospheric conditions and surface characteristics for more precise corrections. Additionally, the effectiveness of the proposed method was quantitatively validated by comparing NDVI values before and after atmospheric correction(Figure 1), leading to the creation of high-precision vegetation index maps. To enhance cartographic representation, this study presents vegetation index maps using advanced visualization techniques including 3D terrain-NDVI integration and before-after comparison maps(Figure 2) that clearly demonstrate correction effectiveness. These cartographic innovations enable better understanding of spatial patterns and support informed decision-making in agricultural and environmental monitoring. Through these enhanced visualizations, this study demonstrates that AI-based atmospheric correction models

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can significantly improve the quantitative utility of remote sensing data in agriculture and forestry applications. The resulting high-precision vegetation index maps provide reliable information for resource management and land-use planning, highlighting the practical value of combining advanced atmospheric correction techniques with innovative cartographic methods.

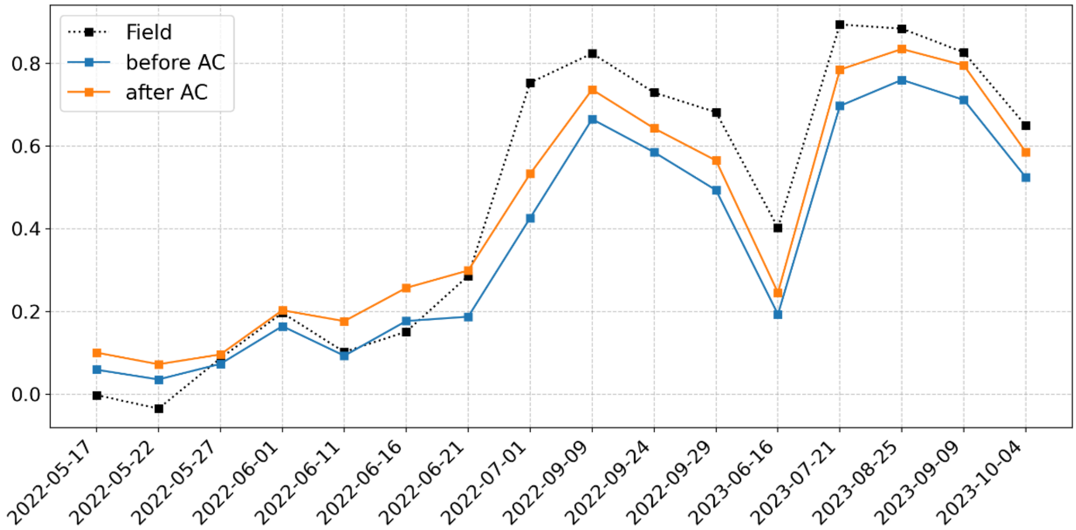

Figure 1. Time series comparison for NDVI.

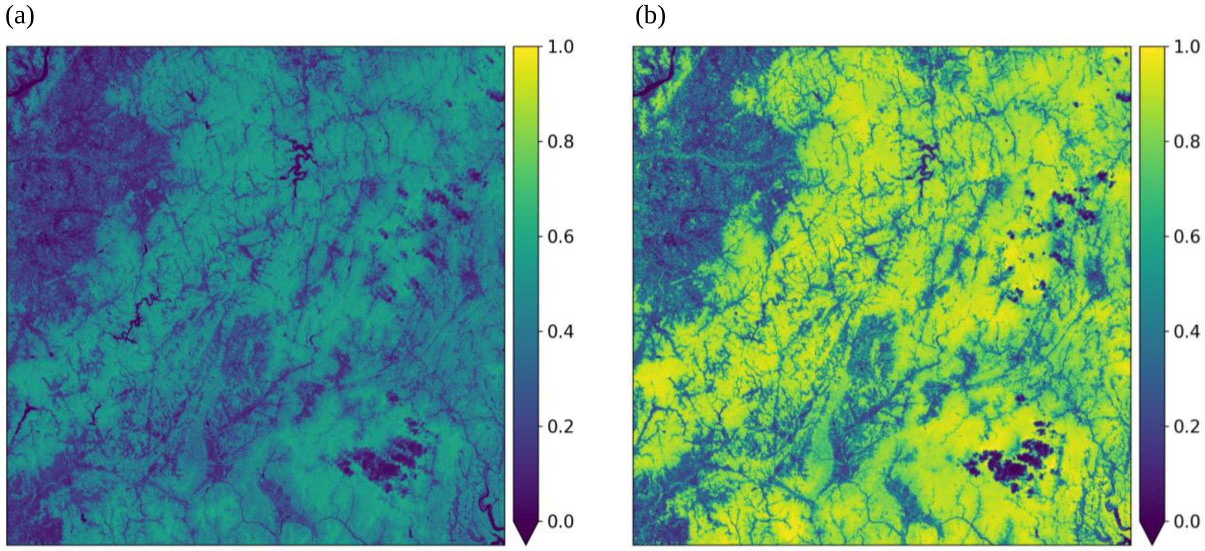

Figure 2. NDVI map before (a) and after (b) atmospheric correction on May 17, 2022.

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