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Deep learning emulators for radiative transfer models: Accelerating crop monitoring in data-scarce regions

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Abstract

Accurate and timely crop monitoring remains a major challenge in data-scarce regions like South Africa's maize belt, where field measurements are limited and conventional radiative transfer model inversion methods are too slow for operational use. This study presents a hybrid approach combining RTM-generated synthetic datasets with a 1D convolutional neural network emulator to retrieve Leaf Area Index and canopy chlorophyll content (CCC) from Sentinel-2 imagery. The deep learning emulator was trained on 150,000 synthetic spectra and fine-tuned with limited field data, then applied to a dryland maize region in Gauteng. Results show the emulator achieved strong agreement with ground-truth measurements (LAI: R2 = 0.91, nRMSE = 8.7%; CCC: R2 = 0.90, nRMSE = 9.3%), accurately capturing field-scale spatial variability. Processing time was reduced by over 10× compared to traditional LUT-based inversion, with full-scene biophysical maps produced in under two minutes. By leveraging the full Sentinel-2 spectral range, the emulator avoided saturation in dense canopies and proved robust across diverse maize conditions. This workflow enables scalable, near real-time crop monitoring with minimal dependence on ground surveys, supporting precision agriculture in resource-limited settings.