Abstract

Remote sensing is a pivotal technology that enables the comprehensive observation and analysis of the Earth's surface, utilizing various sensors to gather information without direct physical contact. This innovative method plays a critical role in monitoring and understanding the dynamic processes occurring on the planet's surface. By employing a wide array of platforms such as satellites, aircraft, drones, and ground-based sensors, remote sensing facilitates the collection of data across different wavelengths of the electromagnetic spectrum e.g., microwave and optical.

This thesis delves into the integration of Synthetic Aperture Radar (SAR) and optical remote sensing techniques, which have emerged as pivotal tools for monitoring vegetation dynamics and biophysical parameters across diverse landscapes. SAR offers unique advantages, such as all-weather and day-and-night imaging capabilities, while optical remote sensing provides high spatial resolution and spectral information. The combined use of SAR and optical data holds immense potential for enhancing our understanding of vegetation dynamics, particularly in agricultural settings like India, characterized by diverse cropping patterns and environmental heterogeneity. By harnessing the complementary strengths of SAR and optical sensors, researchers can derive more comprehensive and accurate insights into vegetation structure, health, and productivity.

The primary objective of this thesis is to investigate the intricate backscattering mechanism of electromagnetic radiation (EMR) across various layers of vegetation and soil interfaces. The focus is on modeling radar backscattering coefficients to extract crucial crop growth parameters and soil moisture content, specifically analyzing VV (vertical-vertical) and VH (vertical-horizontal) polarizations. While numerous robust semi-empirical, empirical, and physical algorithms have been developed for monitoring crop growth conditions and deriving biophysical parameters, the complexities within backscattering responses

over vegetated surfaces and soil necessitate further modification and novel methodological advancements. Leveraging radiative transfer theory, this study extensively employed the developed novel backscattering model to interpret experimental data collected from satellite imagery and ground expeditions. Additionally, polarimetric decomposition analysis is employed to effectively model different scattering components such as volume and surface. To bridge the gap between the scattering model and target parameters, parametric functions and empirical relations are utilized, facilitating the efficient and accurate interpretation of target information retrieval by inversing the model. This retrieval of pertinent vegetation and land surface information significantly contributes to a deeper comprehension of environmental dynamics on both local and global scales. However, while sophisticated electromagnetic scattering models excellently describe complex scattering phenomena based on physics, structural properties, and mathematics, they often involve numerous parameters that aren't available for each observed pixel during retrieval. Consequently, the inversion process of these electromagnetic scattering models becomes computationally intricate and laborious for the extraction of desired target information. Recognizing this challenge, machine learning approaches within the realm of remote sensing have been increasingly explored. In this study, the potential of machine learning techniques, specifically evaluating Gaussian Processes, Artificial Neural Network (ANN) is also undertaken to facilitate retrievals of vegetation biophysical parameters. This exploration aimed to address the complexities inherent in electromagnetic scattering models, providing a potential alternative for more efficient and streamlined retrieval of vital information in remote sensing applications.

This study collectively underscore the efficacy of remote sensing techniques, particularly in the context of estimating land biophyiscal and surface parameters. Gaussian Process Regression (GPR) synergized with Sentinel-1 Dual-Polarized Radar Vegetation Index (DpRVI) and Sentinel-2 Top of Atmosphere (TOA) products demonstrates notable

potential as a robust alternative for precise LAI estimation. Additionally, the modified Water Cloud Model (mWCM) exhibits enhanced accuracy in LAI and SM retrieval, particularly in VH polarization, showcasing significant improvements over traditional methods. The introduction of Volume Power (VP) analysis as a novel approach for vegetation monitoring enriches sensitivity to vegetation scattering, thus enabling more accurate LAI estimates compared to conventional techniques. Moreover, a comprehensive comparison between Sentinel-1 SAR and Sentinel-2 optical data highlights the superior accuracy of SAR-derived LAI estimation, especially when employing VH polarization. Notably, the fusion approach integrating deep learning with multi-source remote sensing data demonstrates remarkable accuracy enhancements, indicating the promising potential of such integration for future LAI estimation endeavors.