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Inversion of radiative transfer model for retrieval of wheat biophysical parameters from broadband reflectance measurements

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ABSTRACT

This study describes the retrieval of wheat biophysical variables of leaf chlorophyll (C_{ab}), leaf area index (LAI), canopy chlorophyll (CCC), and leaf wetness (C_w) from broadband reflectance data corresponding to IRS LISS-3 (Linear Imaging Self Scanner) sensor by inversion of PROSAIL5B canopy radiative transfer model. Reflectance data of wheat crop, grown under different treatments, were measured by hand-held spectroradiometer and later integrated to LISS-3 reflectance using its band-wise relative spectral response function. Three inversion techniques were used and their performance was compared using different statistical parameters and target diagram. The inversion techniques tried were: a look up table with best solution (LUT-I), a look up table with mean of best 10% solutions (LUT-II) and an artificial neural network (ANN). All the techniques could estimate the biophysical variables by capturing variability in their observed values, though accuracy of estimation varied among the three techniques. Target diagram clearly depicted the superiority of LUT-II over the other two approaches indicating that a mean of best 10% solutions is a better strategy while ANN was worst performer showing highest bias for all the parameters. In all the three inversion techniques, the general order of retrieval accuracy was LAI > C_{ab} > CCC > C_w. The range of C_w was very narrow and none of the techniques could estimate variations in it. In most of the cases, the parameters were underestimated by model inversion. The best identified LUT-II technique was then applied to retrieve wheat LAI from IRS LISS-3 satellite image of 5-Feb-2012 in Sheopur district. The comparison with ground observations showed that the RMSE of LAI retrieval was about 0.56, similar to that observed in ground experimentation. The findings of this study may help in refining the protocol for generating operational crop biophysical products from IRS LISS-3 or similar sensors.

1. Introduction

The distribution of vegetation biochemical and biophysical variables in both spatial and temporal extent are important inputs into models quantifying the exchange of energy and matter between the land surface and the atmosphere,

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developing better yield prediction models and detecting abiotic stresses at regional scales. Among various vegetation parameters, leaf chlorophyll content (C_{ab}) and leaf area index (LAI) are of foremost significance [1]. Leaf area index can be used to infer about several ecological processes (e.g., photosynthesis, transpiration and evapotranspiration), estimate net primary production (NPP) of terrestrial ecosystems and is also used in the biosphere–atmosphere interaction models in some General Circulation Models [2]. At the same time monitoring spatial patterns in the biochemical composition of plant foliage is required for understanding the growth dynamics of plant communities [3] and serve as bio-indicators of vegetation stress [4]. The stability, repeated measurement capability, cost effectiveness and global coverage of remote sensing techniques has led to its widespread use to obtain these variables in studies of land surface and atmospheric processes [5,6].

Remote Sensing measurement of plant biophysical parameters can broadly be classified into empirical and analytical/-physical approaches [7,3]. Empirical techniques mostly depends on linear and non-linear combinations of discrete spectral reflectance bands i.e. vegetation indices (VIs) which are used to maximize sensitivity to canopy characteristics while minimizing sensitivity to other, unrelated phenomena such as background effects and viewing geometry [3]. Both approaches have their advantages and disadvantages. The simplicity and computational efficiency of empirical approach makes it highly amenable for large-scale remote sensing applications. However, lack of generality of scale of application remains a fundamental problem with the VIs approach for estimating vegetation parameters. As canopy reflectance results from complex interaction of several internal and external factors [8] which varies significantly in time and space and from one crop type to another, relationship between a single canopy variable and a spectral signature can hardly be expected to be unique [5]. Further, the anisotropic properties of the surface features makes it more complex and to vary with different view angles. Hence, spectral reflectance relationships are site, time and crop specific, making the use of a single relationship for an entire region unfeasible [9].

On the other hand, the analytical/physically-based models describe the transfer and interaction of radiation inside the canopy based on physical laws and thus providing explicit relation between the biophysical variables and the canopy reflectance [5]. Therefore, retrieving canopy characteristics from the inversion of these models is theoretically preferable to fully exploit the information contained in the reflectance signal recorded by remote sensing sensors [10]. Knowledge of the relationship between canopy biophysical characteristics to surface reflectance anisotropy [11,12] provides a strong scientific basis for the application of these models [13]. However, this approach is limited by several aspects not only from the complexity of canopy radiation interaction processes but also from the inversion techniques [14,15]. Selection of appropriate model is often a trade-off between model complexity, invertibility and computational efficiency [14]. The advancement in modeling through detailed radiation interaction descriptions offer great potential for improvement but requires an extensive description of canopy architecture and high computational efficiency [10]. On the other hand from the application side, because of the lack of prior information on the statistical distribution of most land surface attributes, simple low-dimensional radiative transfer models are often preferred for operational purposes [10].

Inversion of physics-based radiative transfer models has grown rapidly in the field of remote sensing of both aquatic and terrestrial environments [16,17]. Different inversion techniques have been proposed for these models, including numerical optimization methods [18–20], look-up table (LUT) approaches [21–23,1,24], artificial neural networks (ANN) [25,14,26,27], genetic algorithm (GA) [28], Principal Component Inversion (PCA) technique [29] and, very recently, support vector machines (SVM) regression [30–32]. The iterative optimization approach can directly retrieve biophysical parameters from observed reflectance without any sort of prior use of calibration or training data. But this method lags behind for its expensive computational requirement [19] making the retrieval of variables unfeasible for large areas. The LUT and ANN methods are computationally efficient than the traditional optimization approach and can be applied on a per pixel basis of satellite images. Moreover, they can be applied to the most sophisticated models without any simplifications. Though look up table technique may provide an efficient alternative, the definition of the cost function to be minimized still remains an open question when the uncertainties and their structure are not very well known [10]. These limitations are sorted out by neural networks which have been increasingly used for reflectance model inversion [33,26]. They are very efficient computationally since the inversion process is not iterative in the application mode. All of the physically based models share the common limitation of the ill-posed nature of model inversion [34,22]; which is observed with different combinations of canopy parameters corresponding to almost similar spectra [5]. Lookup table and neural network approaches require a training database consisting of canopy reflectance spectra together with the corresponding biophysical variables, and their performances rely on the training database and the training process itself.

There is still dearth of ample information on rigorous comparison of the various inversion methods in terms of accuracy and stability, computational time and number of variables obtainable [35,36]. Keeping in mind the problems of these inversion strategies, a field study followed by a regional scale study were undertaken to compare of PROSAIL5B model inversion by look up table (LUT) and neural network approaches to simultaneously derive wheat biophysical parameters of leaf chlorophyll content (C_{ab}), leaf moisture content (C_w), leaf area index (LAI) and canopy chlorophyll content (CCC). Inversion approaches were implemented corresponding to broadband reflectances of IRS LISS-3 (Indian Remote Sensing Satellite Linear Imaging Self Scanning-3) sensor. Two variants of LUT approach were tried as described later and performance of all three inversion approaches was evaluated using ground measured wheat canopy parameters at different growth stages. The best method was applied for the regional scale study. The performance of inversions was evaluated using statistical measures and target diagram.