Study of a Vegetation Index Based on HJ CCD Data's top-of-atmosphere reflectance and FPAR Inversion

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Abstract. The Fraction of Photosynthetically Active Radiation (FPAR) absorbed by plant canopies is a key parameter for monitoring crop condition and estimating crop yield. In general, it is necessary to obtain Top of Canopy (TOC) reflectance from optical remote sensing data in digital number through atmospheric correction procedures before retrieving FPAR. However, there are a few of uncertainties that exist in the process of atmosphere correction and reduced the quality of TOC. This paper presents a vegetation index based on Top-of-Atmosphere (TOA) reflectance derived from HJ-1 CCD satellite for estimating direct crop FPAR. The vegetation index (HJVI) was designed based on the simulated results of a canopy-atmosphere radiative transfer model, including TOA reflectance and corresponded FPAR. The HJVI had taken the advantages of information in the green, the red and the near-infrared spectral domains with the aim of reducing the atmospheric effect and enhancing the sensitive to green vegetation. The HJVI was used to estimate soybean FPAR directly and validated using field measurements. The result indicated that the inversion algorithm produced a good relationship between the prediction and measurement ($R^2 = 0.546$, RMSE = 0.083) and the HJVI showed high potential for estimating FPAR based on the HJ-1 TOA reflectance directly.

1. Introduction
The Fraction of absorbed Photosynthetically Active Radiation (FPAR) is an essential variable in the Global Climate Observing System (GCOS) [1], which can be acquired from remote sensing image. This is because FPAR is one of the most important canopy biophysical variables for crop production estimation [2], vegetation health monitoring [3], drought monitoring [4], and land use change detection [5].

A great number of methods have been investigated for FPAR estimation, which can be grouped into two categories. The first category is the statistical/empirical model based on the relationships between field-measured FPAR and vegetation indices. It has been widely used with high efficiency, as it is suitable for detecting in-field spatial variability. The other category of approaches for FPAR retrieval is physical methods based on the inversion of canopy reflectance model. The canopy reflectance model can clearly describe the transfer and interaction of radiation inside the canopy based on physical laws.

In general, it is necessary to obtain canopy reflectance from the top-of-atmosphere (TOA) radiance of satellite measurements through data pre-processing steps including geometric correction, radiometric calibration and atmospheric correction, before conducting the FPAR model. However, uncertainties were found in the processes of correcting atmospheric, adjacency, topography and surface directional effects, which will bring errors into the estimated FPAR. For example, Gobron et al [6] found that the
influence of TOA radiance uncertainties on the accuracy of the expected MERIS FPAR products is 5% to 10%.

Recently, an innovative concept that retrieval of vegetation biophysical and biochemical variables can be conducted directly using the TOA radiance by inverting a coupled canopy-atmosphere radiative transfer models has been put forward by some scholars. Verhoef et al[7, 8] has successful developed and used a coupled canopy-atmosphere radiative transfer model which integrated PROSAIL and MODTRAN to simulated hyper-spectral multi-angular surface reflectance and TOA radiances. Then the model was applied to estimate forest variables using TOA radiance directly [9, 10]. The same idea was also conducted and validated by Houborg et al[11], who developed the REGularised canopy reFLExtance (REGFLEC) model based on the PROSPECT, ACRM and 6S atmospheric radiative transfer model. The model was used in the estimation of LAI (Leaf Area Index) and leaf chlorophyll content. The most prominent advantage of this kind of models is that the forward modeling will be more accurate and the inversion can be implemented without atmospheric correction [9, 10].

The primary objective of this research is to develop a vegetation index (HJVI) for FPAR estimation based on TOA reflectance directly. First, the empirical relationship between TOA reflectance and FPAR was obtained based on a coupled canopy-atmosphere radiative transfer model. To test the robustness and the ability of HJVI in cropFPAR estimation, a case study of soybean was conducted in this study.

2. Material and Methods

2.1. Study region
The study area, Hongxing Farm, locates in north of Heilongjiang province, China (48° 09' N 127° 01' E). The farm lies within Mid-Temperate Zone characterized by mean rainfall of 555mm and accumulative temperature of 2250 celsius degree per year (>10 Celsius degree). The major crops are soybean, spring corn and spring wheat. In 2011, the proportion of soybean Hongxing Farm was 40%.

2.2. Field data collection
Field measurement was conducted at the study region from 26th, September to 28th, September, 2011, when mostsoybean was at the reproductive stage. A total of 27 groups sampling data (30m×30m area for each sampling site) were obtained in this field data collection. The the FPAR and soil spectral reflectance were measured at each sampling site. All measurements were conducted in cloudless and windless days.

FPAR was measured with the SUNSCAN Canopy Analysis system[12]. Traditionally, four fractions of PAR measurement are required in the FPAR measurement. They are incidence PAR above canopy (PAR0), incidence PAR transmit by the canopy (TPAR), incidence PAR reflected from the canopy (RPARc) and incidence PAR reflected by the soil (RPARg). Then the FPAR can be calculated using followed formula:

\[
\text{FPAR} = \frac{\text{PAR}_0 - \text{TPAR} - \text{RPAR}_c + \text{RPAR}_g}{\text{PAR}_0} \tag{1}
\]

The soil reflectance from 350 nm to 2500 nm was acquired with the SVC field-portable spectroradiometer (HR-768)[13]. The Savitzky-Golay (S-G) smoothing filter was then applied to remove the noise in the reflectance, and then the measured reflectance was resampled to 1 nm revolution to improve the quality of the data.

2.3. Remote sensing data and processing
One scene of cloud-free HJ 1A-CCD2 image at 30m resolution was acquired on 26th, August, 2011. The center sun zenith and azimuth were 40 and 150 degree, respectively. In order to compute TOA reflectance, the geometric correction and the radiometric calibration were conducted in the data pre-
processing. In detail, the geo-referenced Landsat Thematic Mapper (TM) provided by the United States Geological Survey (USGS) was used as reference images in geometric correction. Then, the coefficients of radiometric calibration provided by the China Center for Resource Satellite Data and Application (CRESDA) was used to obtain the TOAS reflectance.

2.4. Methodology

In this study, the designing of an optimal HJVI based on HJ-1’s CCD TOA reflectance includes two major steps: (a) forward reflectance modeling to generate TOA reflectance and FPAR; (b) designing the HJVI based on the TOA reflectance and FPAR. Details of the procedure are given in the following sections.

2.4.1. Forward reflectance modelling

The coupled radiative transfer model[7, 8], which intergraded the leaf optics model (PROSPECT), the canopy reflectance model (SAIL), and atmospheric radiation transfer model (MODTRAN), was used to simulate the multi-bands TOA reflectance of HJ-1 CCD. For simulating the leaf reflectance and transmittance, chlorophyll a and b content (Cab), dry matter content (Cm), equivalent leaf water content (Cw), and leaf structural parameters (Ns) are acquired in the PROSPECT. For simulating canopy reflectance, LAI, leaf angle distribution (LAD), hot-spot size and soil reflectance are acquired in the SAIL. In the MODTRAN, visibility (km) and elevation (km) are acquired for simulating the atmospheric environment. Moreover, external parameters including satellite view angle, sun zenith and azimuth angles were also acquired in both SAIL and MODTRAN models.

For the parameters setting, parts of input parameters (e.g. LAI) were set in a range of value assuming uniform distributions, while other parameters like Ns were set in constant value. The background reflectance of the model was replaced by the field-measured soil reflectance. All above-mentioned input variables are listed in Table 1. A total of 6,000 simulations including the TOA reflectance and FPAR were used in this study.

| Parameter | Units | Range or mean value | Class |
|-----------|-------|---------------------|-------|
| SZA       | degree| 45                  | 1     |
| VZA       | degree| 40                  | 1     |
| RAA       | degree| 150                 | 1     |
| Visibility| Km    | 25-55               | 7     |
| H2O       | -     | default             | 1     |
| O3        |       | Default             | 1     |
| Elevation | km    | 0.5                 | 1     |
| LAI       | m²/m² | 0.1-7.0             | 20    |
| Cab       | ug cm⁻²| 16.5-85.5          | 10    |
| Cw        | g cm⁻²| 0.0113              | 1     |
| Cm        | g cm⁻²| 0.0053              | 1     |
| ALA       | degree| 30-80               | 5     |
| Hotspot   | -     | 0.5/LAI             | 20    |
| Ns        | -     | 1.55                | 1     |

2.4.2. HJVI designing

There were two purposes in the designing of HJVI in this study. The first one was to reduce the influence of soil background and minimize the influence of atmosphere. Thus the blue band information and canopy background adjustment were considered in the HJVI according to the concept of Enhanced vegetation index (EVI) [14]. The other purpose was to enhance the green information based on the green band. A few of studies have found that the green band is useful for separating the green vegetation and other non-vegetation part of the canopy and is suitable for measuring the rate of
photosynthesis and monitoring vegetation stress.[15]. Based on these two purposes, the expression of HJVI can be written as follows:

$$\text{HJVI} = \frac{C_1(NIR - RED)}{(C_2 \times RED + C_3 \times GREEN - C_4 \times BLUE + C_5)}$$

(2)

Where, BLUE, GREEN, NIR and RED are the simulated TOA reflectance of the HJ-1 CCD’s four bands, respectively, C1~C5 were the coefficients, HJVI was equal to FPAR.

The least squares fitting method, an optimization procedure, was applied to retrieve the optimal value of coefficients. In this process, the C1 was set a range of 0.1 to 1.0, C2~C5 were set between 1.0~10.0 at 0.5 interval.

3. RESULTS AND DISCUSSION

3.1. FPAR estimated with HJVI

All the parameters had been derived by the least squares fitting method. And the optimal value of C1~C5 were listed in Eq (3).

$$\text{HJVI} = \frac{0.76(NIR - RED)}{(RED + 2\times GREEN - 8.5\times BLUE + 1.0)}$$

(3)

The result of the least squares fitting method showed that the optimal value of C1~C5 were 0.76, 1.0, 2.0, 8.5 and 1.0, respectively. Then, the image of HJ-1 CCD which had been pre-processed was used to calculate HJVI and map soybean FPAR (Fig.1).

![Figure 1. Spatial distribution of FPAR retrieved from HJVI](image)

3.2. Validation

Ground observation data of FPAR collected in the soybean field (n=27) was used to validate the FPAR retrieved directly from the HJVI (Fig.2). The coefficient of determination ($R^2$) between the measured FPAR and the predicted FPAR was 0.546, The root-mean-square deviation( RMSE ) was 0.083. The slope was 0.899 and the intercept was 0.062. All of these showed that the result was satisfactory. The validation showed that the HJVI base on TOA reflectance has a high potential in crop FPAR estimation.
**4. CONCLUSION**

The uncertainties came from the pre-processing of satellite data have significant impacts on the accuracy of vegetation biophysical variables retrieval. This study showed that it has a high possibility to estimate canopy biophysical variables (e.g. FPAR and LAI) using TOA reflectance directly, for example, the vegetation index developed by the TOA reflectance directly. However, some new problems had been found in this study and needed be considered and discussed in the further study.

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**References**

[1] 2010 A Framework for Terrestrial Climate-Related Observations and The Development of Standards for the Terrestrial Essential Climate Variables: Proposed Workplan. In: Report to the 33rd session of the Subsidiary Body for Scientific and Technological Advice,

[2] Prieto-Blanco A, North P R J, Barnsley M J and Fox N 2009 Satellite-driven modelling of Net Primary Productivity (NPP): Theoretical analysis Remote Sensing of Environment113 137-47

[3] Gobron N, Pinty B, Aussedat O, Chen J M, Cohen W B, Fensholt R, Gond V, Huemmrich K F, Lavergne T, Melin F, Privette J L, Sandholt I, Taberner M, Turner D P, Verstraete M M and Widlowski J L 2006 Evaluation of fraction of absorbed photosynthetically active radiation products for different canopy radiation transfer regimes: Methodology and results using Joint Research Center products derived from SeaWiFS against ground-based estimations Journal of Geophysical Research-Atmospheres111

[4] Rossi S, Weissteiner C, Laguardia G, Kurnik B, Robustelli M, Niemeyer S and Gobron N 2008 Potential of MERIS fAPAR for Drought Detection Proc. of the '2nd MERIS / (A)ATSR User Workshop', Frascati, Italy 22–26 September 2008 (ESA SP-666, November 2008)

[5] Marcal L, Zeng Y and Rowhani P 2010 Climate and Land-Use Effects on Interannual fAPAR Variablity from MODIS 250 mData Photogramm. Eng. Remote Sens.76 807-16
[6] Gobron N, Pinty B, Aussedat O, Taberner M, Faber O, Melin F, Lavergne T, Robustelli M and Snoeij P 2008 Uncertainty estimates for the FAPAR operational products derived from MERIS - Impact of top-of-atmosphere radiance uncertainties and validation with field data Remote Sensing of Environment112 1871-83

[7] Verhoef W and Bach H 2003 Simulation of hyperspectral and directional radiance images using coupled biophysical and atmospheric radiative transfer models Remote Sensing of Environment 87 23-41

[8] Verhoef W and Bach H 2007 Coupled soil-leaf-canopy and atmosphere radiative transfer modeling to simulate hyperspectral multi-angular surface reflectance and TOA radiance data Remote Sensing of Environment109 166-82

[9] Laurent V C E, Verhoef W, Clevers J G P W and Schaepman M E 2011 Inversion of a coupled canopy–atmosphere model using multi-angular top-of-atmosphere radiance data: A forest case study Remote Sensing of Environment115 2603-12

[10] Laurent V C E, Verhoef W, Clevers J G P W and Schaepman M E 2011 Estimating forest variables from top-of-atmosphere radiance satellite measurements using coupled radiative transfer models Remote Sensing of Environment115 1043-52

[11] Houborg R, Anderson M and Daughtry C 2009 Utility of an image-based canopy reflectance modeling tool for remote estimation of LAI and leaf chlorophyll content at the field scale Remote Sensing of Environment113 259-74

[12] Fei Y, Bai Z, Kai-shan S, Zong-ming W, Jin-chun Y, Dian-wei L, Jing-ping X, Geography N I o, Agroecology, Sciences C A o, 130012 C, University P R C G, 100039 B, Library P R C, Business J, College T, 130062 C and P.R.China 2007 Hyperspectral Estimation of Corn Fraction of Photosynthetically Active Radiation Agricultural Sciences in China 1173-81

[13] Corporation S S V 2010 HR-1024/HR-768 USER MANUAL

[14] Jiang Z, Huete A R, Didan K and Miura T 2008 Development of a two-band enhanced vegetation index without a blue band Remote Sensing of Environment112 3833-45

[15] Gitelson A A, Kaufman Y J and Merzlyak M N 1996 Use of a green channel in remote sensing of global vegetation from EOS-MODIS Remote Sensing of Environment58 289-98