Comparisons of MODIS LAI products and LAI estimates derived from Landsat TM

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Abstract—Numerous pre- and post-launch validation researches have been applied on the MODIS LAI products. However, the validation activities were mainly located in North America, Europe and Africa. The validated vegetation types were mainly focused on woodlands (broadleaf forest, coniferous forest and shrubland) and savannas (woody savannas and savannas). In this study, we evaluated the Collection 4 MODIS LAI (MOD15A2) products in North China Plain, with emphasis on the croplands, by: (1) deriving empirical LAI validation maps, based on in situ measurements and Landsat Thematic Mapper (TM) images; (2) conducting initial MODIS validation exercises to assess the quality of MODIS products. The results indicated the MODIS LAI products could resemble the general patterns of the LAI seasonal variation of vegetations in North China Plain, but MODIS LAI algorithm had underestimated LAI values obviously (down to 2-3 m²/m²). Biome misclassification and cloud effect were thought to be the main reasons for the significant underprediction of MODIS LAI products.

Keywords—leaf area index (LAI); Moderate Resolution Imaging Spectroradiometer (MODIS); Landsat Thematic Mapper (TM); validation; North China Plain (NCP); winter wheat

I. INTRODUCTION

The MODIS Land Discipline Group (MODLAND) has developed a suite of higher level (beyond at-sensor radiance) products relevant to earth system science and global change research [1]. These standard MODIS data products include Leaf Area Index (LAI), and are publicly available through the Earth Resources Observation System (EROS) Data Center Distributed Active Archive Center. LAI is defined as one sided green leaf area per unit ground area in broadleaf canopies and as the projected needle leaf area in coniferous canopies [2]. Validation of these data products before application is crucial, both to establish the accuracy of the products for the science-user community and to provide feedback so that the data processing algorithms and product-oriented models can be improved [3].

Numerous pre- and post-launch validation researches have been applied on the MODIS LAI products. Prior to the launch of MODIS, the algorithm for retrieve of LAI from MODIS surface reflectance was prototyped with Landsat TM, Polarization and Directionality of the Earth's Reflectance (POLDER), and Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data [4]. The post-launch validation activities were focused not only on spatial upscaling by comparing BigFoot- and MODIS-derived surfaces [5, 6], but also on temporal scale [7, 8]. However, validation activities were mainly located in North America [9], Europe [8] and Africa [10]. The validated vegetation types were mainly focused on woodlands (broadleaf forest, coniferous forest and shrubland) and savannas (woody savannas and savannas). Moreover, there are contradictory results for the assessment of MODIS LAI product accuracy [10, 11, 12]. Therefore, as one of the most important grain production bases of China, North China Plain (NCP) were deserved to be the validation site for MODIS LAI products in Asian temperate zone.

In this study, we evaluated the Collection 4 MODIS LAI (MOD15A2) products in North China Plain with emphasis on the cropland, by: (1) deriving empirical LAI validation maps, based on in situ measurements and multi-temporal Landsat TM images; (2) conducting initial MODIS validation exercises to assess the quality of MODIS products, and analyzing the potential problem for agricultural application.

II. STUDY AREA

North China Plain (NCP) is one of the most important grain production bases of China and accounts for about 50% of wheat (Triticum aestivum L.) and 35% of maize (Zea mays L.) production in China. The study area is located in NCP (Fig. 1), consists of 28 counties of Hebei province, and covers 114°15'E-115°40'E longitude by 36°30'N -38°20'N latitude and about 21470 km². The land use in this area is dominated by the intensive dual-cropping system based on winter wheat and summer crops, including maize, soybean, cotton and sorghum.
The study area lies in a temperate semi-arid and semi-humid monsoon climate, with mean annual temperature 12.4°C, mean annual global radiation 537 KJ/cm², and mean annual precipitation 550 mm. The majority of precipitation arrives during the summer monsoon between July and September. The average elevation is about 70m above the sea level. The dominant soil type is loam, with plenty of organic matter. Growing season of winter wheat is from early October to early or mid June, and for maize is from early or mid June to the end of September.

III. MATERIALS AND METHODS

A. Sample Design and Field Measurements

The LAI measurements were only taken in the fields of winter wheat. There were 85 field measurement sites evenly located in the 28 counties of study area, with about 3 sites for each county (Fig. 1). The location of sites in each county was decided according to the typical growth environment, agronomic treatment and the dominant cultivars of winter wheat. The field measurements for each site are fixed on one 30m×30m plot, where LAI were measured at five to nine subplots. Plot locations were determined using the real-time differential GPS.

LAI was measured using the standard, direct harvest method for each plot from Oct. 2003 to June 2004. Destructive samples began shortly after the emergence of winter wheat and continued through the milk stages. LAI of winter wheat were measured monthly before hibernation and biweekly after recovering. The leaf areas of the samples from subplots were averaged and combined with the plant density to get estimates of LAI for each plot.

B. LAI Estimates Derived from Landsat TM

The whole study area was within the cover area of Landsat TM image (Path 124/Row 34). During the growing season of winter wheat in 2004, there were only three cloud-free TM images available for this study, acquired on March 7th, April 8th and June 11th, 2004. The three TM images were initially geo-referenced to the UTM (WGS84) projection by using 120 Ground Control Points (GCPs) obtained from one existing geo-rectified TM image. To extract the surface reflectance, the raw digital number values were converted to spectral radiance and top-of-atmosphere reflectance according to the procedures outlined in [13]. Then, we performed a further atmospheric correction by using the atmospheric code 6S [14] with the standard model parameters.

Land cover classification is an important step to assure accurate retrieval of LAI for winter wheat. All three TM images were applied to the Tasseled Cap Transform firstly. Then, the brightness, greenness, and wetness for three dates were combined into one file for supervised classification.

Regression analysis has been a popular empirical method of modeling the relationship between spectral data and LAI [5, 15]. In this study, we used a regression approach to model LAI of winter wheat from TM images. Five of the most common vegetation indexes (RVI, NDVI, DVI, RDVI and MSAVI2) were selected for LAI estimation. The Curve Estimation procedure (SPSS for Windows, SPSS Inc., 2001) was used to estimate the relationship between field-measured LAI in 85 sites and TM images acquired on March 7th and April 8th, with spectral VIS as the independent variable. The investigated models include linear, logarithmic, quadratic, cubic, power, inverse and exponential model. Validation of these models was performed by comparing differences in the adjusted R² coefficient and root mean square error (RMSE).

C. MODIS LAI Products

MODIS LAI product (MOD15A2) is at 1-km spatial resolution and at an eight-day interval. The MODIS LAI algorithm is based on three-dimensional radiative transfer theory and is developed for inversion using a look-up table (LUT) method (main algorithm) [16, 17]. LUTs are generated for each biome by running the algorithm for various combinations of LAI and soil type. A backup algorithm, based on relations between NDVI and LAI, associated with a biome classification map, is utilized to retrieve LAI values if the main algorithm fails. The products also include extensive quality control (QC) information regarding cloud and data processing conditions. The MODIS LAI products (collection 4) are available for the public from the Earth Observing System Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/) and are in the Sinusoidal Projection. To compare MODIS and TM products, we used the MODIS Reprojection Tool (MRT, http://edcdaac.usgs.gov/landdaac/tools/modis/) to mosaic, spatially subset and reproject MODIS products into UTM (WGS84) projection. In this research, the Collection 4 MODIS LAI (MOD15A2) products from tile h27v05, h27v04, h26v05 and h26v04 were used for evaluation.

IV. RESULTS AND DISCUSSION

A. Landsat TM LAI Model

The regression relationships tended to be highly significant for each vegetation indices, used in this study. The adjusted R² of the best regression model for each pair of SVI and LAI were
higher than 0.70. This indicated that much of the variation occurring in LAI of winter wheat could be explained by using the spectral \( V_{ii} \)s from multi-temporal TM images. According to the results of statistic analysis, it was decided to construct LAI model by using the exponential relationship between surface-reflectance-derived DVI and field-measured LAI. The LAI model is applied for all pixels of winter wheat in the study area.

**B. Comparisons with MODIS LAI Products**

The 8-day composite MODIS 1km LAI products for the entire study area, acquired on March 5th-12th, April 6th-13th and June 9th-16th 2004, were listed in Fig. 2. The upper-left corner of MOD15A2 for March 5th-12th missed, because the Collection 4 MOD15A2 from tile h26v04 and h26v05 were not available from the EROS Data Center. The land use in the area was dominated by the intensive dual-cropping system based on winter wheat and summer maize. From Fig. 2, it was obvious that MODIS LAI products accommodated phenological and structural variability correctly for the study area. The dominant biome, the grasses and cereal crops (winter wheat), showed a relative low LAI value in March corresponding to the recovery or begin-growth after hibernation stage, and indicated a rapid increase in April and a steep decrease in June due to the harvest. However, the needle forest and the broadleaf crops (such as: cotton) kept a relative low LAI in March and April, and changed to a relative high LAI since June.

We also compared the relationships among TM LAI (30m), TM LAI (1000m) and MODIS LAI products (1000m) across all field measurement sites. TM LAI maps with the resolution of 1000m were obtained by average algorithm from TM LAI (30m). Fig. 3 showed the correlation between field-measured LAI and TM LAI (30m), between TM LAI (30m) and TM LAI (1000m), and between TM LAI (1000m) and MODIS LAI products (1000m) respectively. By comparing these scatterplots, it is one obvious difference between TM LAI (1000m) and MODIS LAI products that MODIS LAI products underpredicted LAI values for winter wheat, especially in April. The results indicated that Collection 4 MODIS-based LAI estimates were considerably lower (down to 2-3m$^2$/m$^2$) than those based on TM LAI in winter wheat fields of the study area in 2004.

**V. DISCUSSION AND CONCLUSIONS**

Validation of MODIS global data products is crucial, both for the science-user community and for the data-developer. How to extrapolate scarce field data from sampling points to a sufficiently extended area is the biggest challenge for validation of MODIS LAI products. One way of doing this is to employ both field measurements and high-resolution satellite data (10-30m) to produce validated fine-resolution LAI maps over the study area. In this study, multi-date Landsat TM images have been proved to be available for MODIS products validation. The results indicated that MODIS LAI products accommodated phenological and structural variability correctly in North China Plain. However, collection 4 MODIS-based LAI estimates were considerably lower (down to 2-3m$^2$/m$^2$)
than those based on TM LAI in winter wheat of the study area of North China Plain in 2004.

There are many factors having effects on the performance of MODIS LAI algorithm, such as input and model uncertainties, reflectance saturation, multi-band retrievals combination, soil background and so on [2]. In this study, biome misclassification, cloud effect and spatial resolution may be the main reasons for the significant underprediction of MODIS LAI products.

Quality control (QC) measures are produced for every MODIS LAI products [2]. The quality control information is represented by 2 data layers in the file of MOD15A2 products. As users, we should consult the QC layers of the MODIS LAI product to analyze and select reliable retrievals. From the quality control information for three MODIS LAI maps in this study, the proportion of pixels covered by cloud is 55.80% for MODIS LAI (March 5th-12th), 20.22% for MODIS LAI (April 6th-13th) and 1.55% for MODIS LAI (June 9th-16th). The main algorithm fails when the pixel's reflectance data are corrupted due to clouds or atmospheric effects. NDVI, in these cases, is close to zero, therefore, the backup algorithm outputs low LAI values. Therefore, cloud effects should contribute to the underestimated for MODIS LAI (March) and MODIS LAI (April) greatly, especially for the former.

The Retrieval Index (RI) was used as one of the examine coefficients for biome misclassification. They suggested that misclassification could be detected by RI, mean LAI and the histogram of the retrieved LAI distribution [2]. But in fact when misclassification happened in distinct biomes such as GCC (grasses and cereal crops) and BLF (broadleaf forests), the method was effective. The misclassification can be identified and modified. When in the case of misclassification between spectrally and structurally similar biomes like in this study for GCC and BCR (broadleaf crops), it was difficult to found that the wrong biome has been accepted as the input for the MODIS LAI algorithm. By comparing the TM land cover map with MODIS land cover map (MODI2Q1 products), misclassification has been proved to exist between the main biomes (GCC and BCR).

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