An Inverting Approach of BRDF for Wheat in North China Using NOAA—AVHRR Image*

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Abstract Because the relationship between LAI and NDVI is not unique and vary with structure of vegetation. We adopted NOAA—AVHRR images in the northern great plain to map distribution of the leaf area index (LAI), average leaf angle (ALA) and so on, instead of using NDVI that is very popularly used in China. This paper first validated N-K inversion algorithm using measurements of SE590 spectra-radiometer in Yucheng Experimental Station. The optimum conditions for inversion are that view zenith ranged from 40 or so, view azimuth ranged −10 to 10.

A comparison between inversion result and NDVI is conducted. There are two advantages to be obvious for using inversion algorithm of N—K model. 1) Ecologic parameters can be inverted directly without using correlation statistic method. 2) More than two parameters such as LAI, ALA, LAD can be obtained for n>2 inversion, whereas NDVI is just itself one parameters. 3) The bidirectional effect can be considered in the inversion algorithm, but NDVI can not. As a result, although improvement is necessary for the inversion algorithm in future, it is worth to test and apply that in wider range.

Key words Inversion, Leaf area index, Simultaneous measurement

1 INTRODUCTION

Although the normal difference vegetation index (NDVI) has became very popular method to estimate LAI, the relationship between LAI and NDVI is not unique and vary with structure of vegetation. In order to obtain more precise vegetation information from remote sensing data, during recent decade a number of bidirectional reflectance distribution function models (BRDF) have been developed. Obvious progress has obtained in quantitative expression of function between BRDF and biophysical characteristics of vegetation[1−10].

The most authors above mentioned undertake research on both BRDF modelling and its inversion. Goel *et al* have published several excellent efforts in inversion of biophysical parameters[3,11]. However inversion of the models possess more complexities and less determinacy. In term of mathematical inferring, so long as a parameter does appear in the expression of the reflectance, of course it can be inverted. In fact, although a parameter does appear in the expression of reflectance, it appears only in a term which is much smaller than the predominant term, then it can not be inverted. Various reflectance measured in various zeniths and azimuths of both the sun and view are basic information source, but if this kind of vegetation canopy is a Lambertian or near Lambertian that can not obtain vegetation structure information from multiangle information of canopy. When two canopy parameters appear only as a product for example

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(rxcos0), where 0 is zenith angle of the leaf upper size normal, these two parameters can not be individually inverted.

Therefore when a BRDF model is inverted, these simple limitations should be considered to invert vegetation parameters effectually.

First this paper will validate N-K inversion algorithm using measurements of SE590 spectroradiometer in Yucheng Experimental Station on Remote Sensing. A sensitive analysis of the inversion was discussed. Secondly we are going to adopt NOAA-AVHRR images in the northern great plain to calculate distribution of the leaf area index and average leaf angle instead of using NDVI. Simultaneous measurements was carried out with NOAA-AVHRR when which was passing over Yucheng experimental area. The simultaneous measurements will be able to be used for both calibrating input data of NOAA-AVHRR image and validating output resuls. And a comparison between inversion result and NDVI is conducted in this paper.

2 INVERSION ALGORITHM AND SELECTING OPTIMAL INVERSION CONDITION

We adopted a minimum merit function F to invert parameters that is used in some literatures[3,7] before of sensitive test and the selection of the optimum inversion condition. The merit function F reaches minimum if the calculated values of reflectance correspond best to the measured values. As a result, the inversion algorithm become to search the minimum of the merit function F which can expressed as[7]:

$$F(x) = \sum_{j=1}^{m} \frac{(\rho_j^* - \rho_j)^2}{\rho_j^*} + \sum_{j=1}^{9} [(x_i - x_{i,b})2w_i]^2 \qquad (1)$$

Where m is the number of measurements, j is the number of the parameters that we want to invert, ρ_j^* p_j are values measured and calculated respectively, $x_{i,b}$ is the value of the corresponding parameters on the boundary of the given region, $w_i = 0$ if x_i is in between maximum and minimum of x_i, which are given a priori, Otherwise $w_i = w$ which is given constant. The iterations are not repeated until the difference between predict and measured reflectance reaches minimum. The parameters given in final iteration are just inversion results what we expected.

A 10 dimensional merit function is necessary if we want to invert 10 parameters. There are reflectance of 256 wavebands from 0.40 μm to 1.10μm in one measurement by means of SE590 spectroradiometer. Unfortunately, we can not invert 256 parameters using one time of measurement only, because very high correlation exists among visible bands (0.4—0.75μm) and among the near infrared bands (0.75—1.10μm). As a result we selected one reflectance only in the red band and the near infrared respectively. As a rule, we need to 5 measurements in different 5 view angles or 5 solar angles which make a 10 dimensional merit function (n=10) that uses a key array. The first n value is the most significant. The most important and the most useful parameter ought to be first n value. The number of the free parameters depend on the number of the reflectance values. If n=2, one or two credible parameters can be got only.

Selecting of the optimal inversion condition means that we find a range of inputs of inversion, under the range the ratio of signal with noise reaches maximum, error of inversion reaches minimum in the inverting algorithm. It involved: 1) selecting of optimum view and solar angles and wavebands; 2) determination of range for initial input value; 3) coordinating of member of free parameters. The optimal condition is based on the sensitive analysis and the investigation of field experiments.

N-K model was validated by a set bidirectional reflectance of the barley canopy which was measured in the principal plane with the airborne photometer TSFM-4M in Estonia[7]. We test the sensitivity of inversion algorithm using directly leaf area index which can estimating biomass, net productivity, and using directly leaf angle distribution, average leaf angle which can roughly recognize crop type. Those parameters are the most useful and anticipated in application fields.

Therefore we adopted leaf area index as main parameter to evaluate the sensitivity of the inversion algorithm. Fig. 1 show a relationship between LAI and the reflectances in two bands. In terms of Fig. 1, when the red band reflectance (RR) is 0.03 and other parameters keep reasonable experimental values, 0.1 difference of NIR can result in 0.34, 1.26, 1.81 LAI differences in 0.15—0.35, 0.35—0.45, 0.45—0.55 ranges of NIR respectively. When RR is 0.04, 0.1 difference of NIR can result in 1.15, 2.76, 3.45 LAI differences in 0.15—0.35. 0.35—0.45, 0.45—0.55 ranges of NIR respectively. But the RR is changed from 0.03 to 0.04, LAI is changed from 1.47 to 1.02 (INR=0.15) and from 5.73 to 5.93 (INR=0.55). From above values we can see that the INR is more sensitive than RR in the inversion and the sensitivities are different in different value of canopy reflectance. We also see that the more sensitive, the more precise input data have to be given in inversion when RR is 0.03, accuracy of changing in NIR should reaches 0.294, 0.079, 0.055 respectively to guarantee accuracy of inverting with LAI=1. When RR is 0.04, accuracy of changing in NIR should reaches 0.087, 0.036, 0.029 respectively.

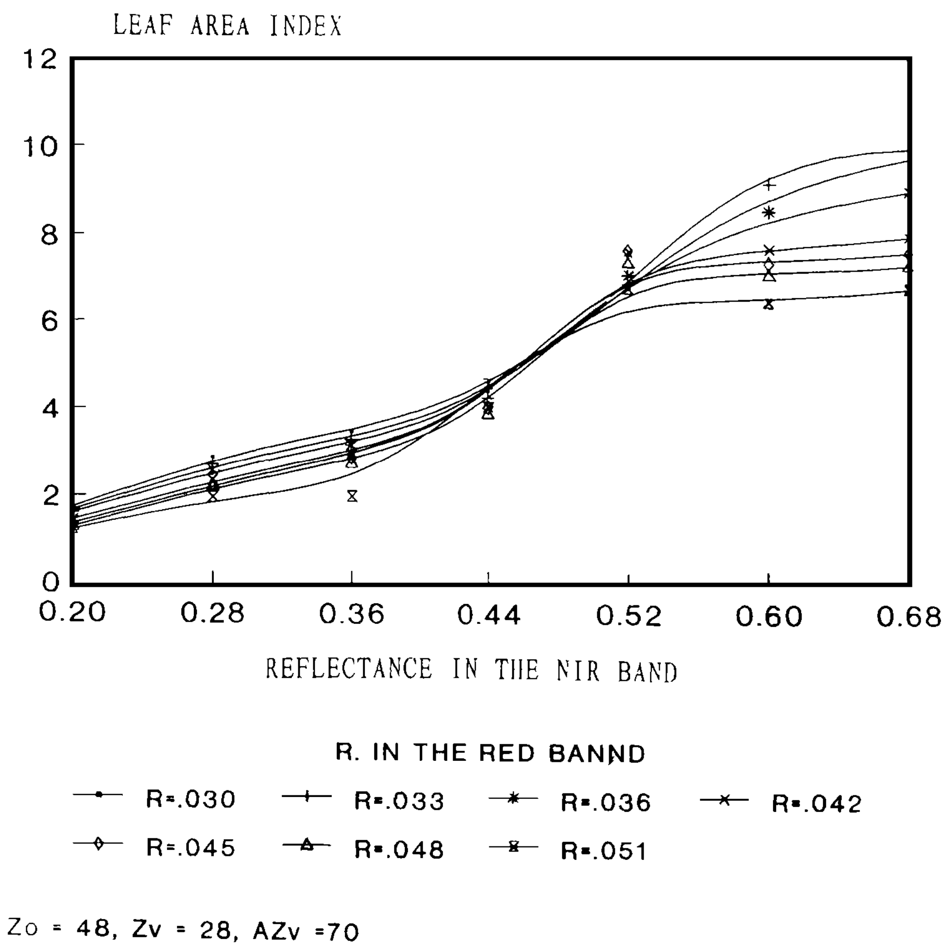


Fig. 1 Sensitivity of inversion (for different bands)

As general rule, the change of canopy reflectance with view and solar zenith and azimuth are sensitive near by the hot spot position. For the other angles its sensitivity decrease obviously. The hot spot effect can be seen in −5 to +5 of solar azimuth and −5 to +5 of solar zenith. In the hot spot range, increments or decrements of the reflectance varied with view zenith and azimuth are larger than the other range. If the view angle are selected in the hot spot range, inversion precision can be improved. But the condition can not often be met in actual application. The view zeniths in an actual range of NOAA—image on May

3, 1993 are from 27 at the south-west corner of the image to 39 at the north—east corner of the image. The view azi-muth are from 65 at the north-west corner to 75 at the north—east corner (Azimuth of viewing from south toward north is defined as zero, and increases from south turning to east gradually in this paper). The azimuth of the primary plane is 30 or so when the NOAA satellite passes over the Yucheng Experimental Site. As a result the view azimuth is more than 30 and the view zenith is more than 10 apart from the hot spot. The sensitivity is not very high for view angles of NOAA—AVHRR image.

Fig. 2 show leaf area index (LAI) varied with view zenith. The LAI is inverted by using the algorithm while keeping the identical reflectances the two bands. The change of LAI with view zenith is not very large. For the algorithm, the initial inputs of parameters are important. They can be justified to reasonable values between maximum and minimum through the inversion process.

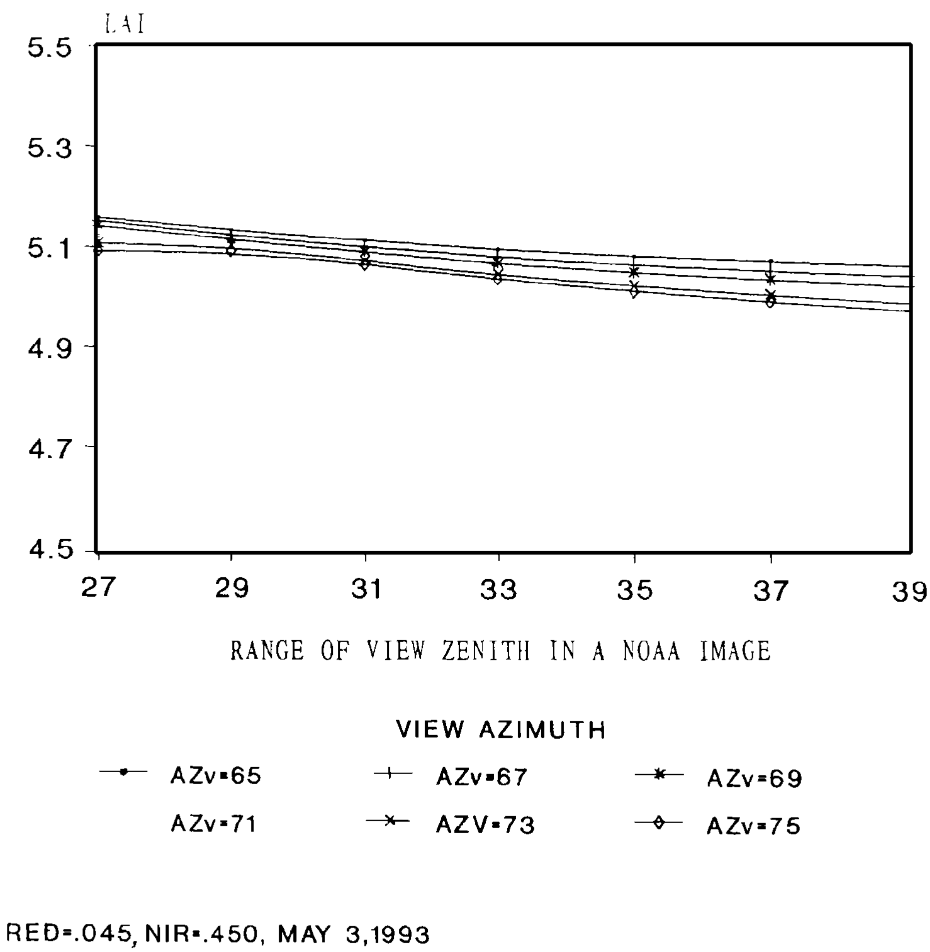
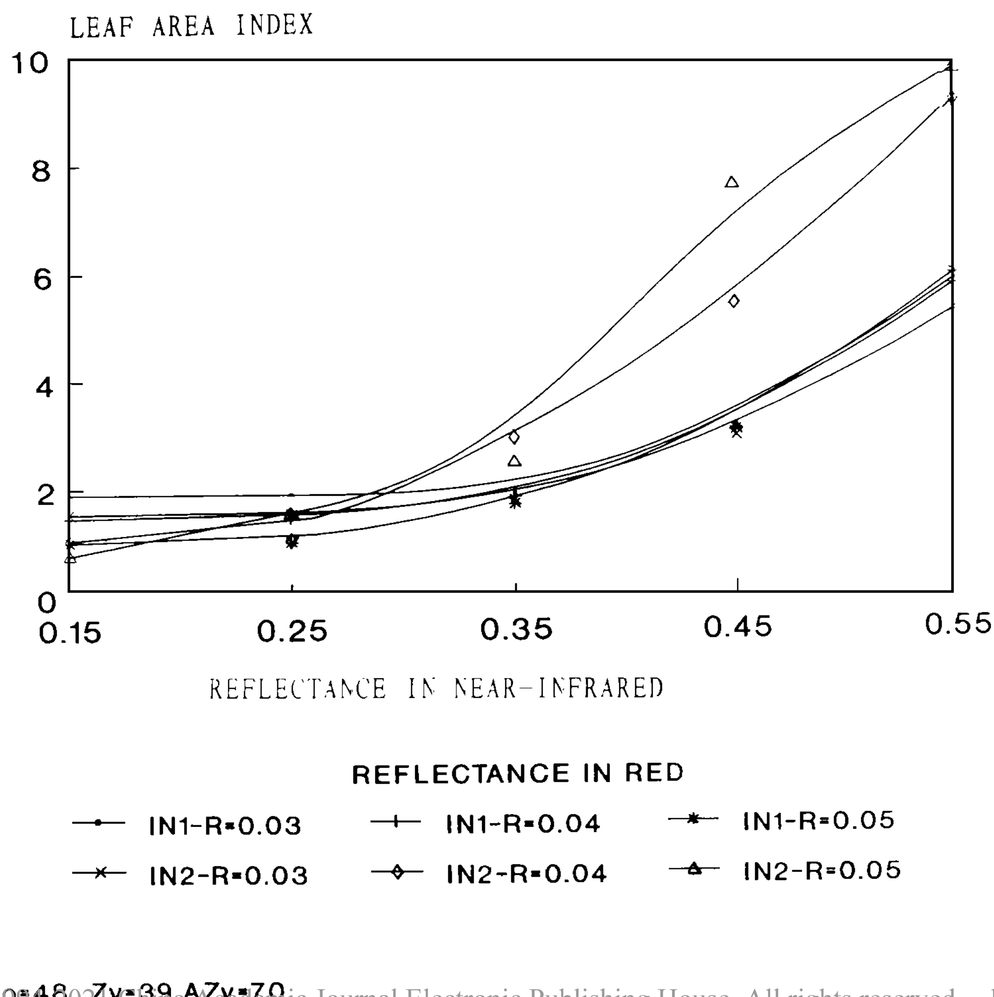


Fig. 2 Sensitivity of inversion (for different initial inputs)

Because the sensitivity on some parameters may be low in certain situations, and inversion turns to more complicated with increasing number of free parameters. Possibilities to compensate each other by different parameters increase. Therefore n = 10 may not work very well. In addition, in actual inversion using NOAA-AVHRR images, more number of reflectance inputs mean more images in different time or date which can cause more troublesome in atmosphere correction and image registration proceeding. If we adopt n = 10 in inversion algorithm, namely, 5 NOAA AVHRR images are necessary, we have to gather them for 5—7 days when the surface condition does not have obvious change. Three problems rose for the situation· First problem is that atmosphere condition for 5—7 days cause obvious change· We need to do more atmosphere correction· Even though some atmosphere correction models just like 6s model have been developed, so far those models are approximate, the errors exist obviously· No doubt, errors accumulated in 5 times (n=10) atmosphere correction are larger than error in 1 time (n=2) correction· Second problem is that geometric position of ground objects are different in different date images which have different view and solar angles· In terms of recent technology of image processing the best precision of the geometric correction or registration reaches half pixel for NOAA-AVHRR images· Most case can reach 1 to 2 pixels only· Certainly, as a result geometric error caused by image in different date is larger than that in the same time· Third problem is, in fact, the canopy of the wheat varies quickly from April to May· It is hard to keep the same surface condition for 5—7 days· For this reason we deemed the number of free parameters n=2 is realistic and feasible, though two parameters can be inverted only·

While the amount of free parameters equals two (n =2), the initial inputs of the other parameters should be set carefully based on previous knowledge and ground surface measurements except for LAI and LAD or ALA, for which a appropriate value can be adjusted through iteration code· Even though n=10, vectors from first to third are significant in the key array only· The other vectors in the key array are not significant, i·e· if the initial inputs of the other vectors are not restrained and adequate values are not guessed, larger error could be caused· As a result different initial inputs of the other parameters can affect the inversion of LAI and ALA· Fig·3 show different inversion result by using different two set of initial



Fig· 3 Sensitivity of inversion (for different bands) inputs. The reflectance and transmittance of the individual leaf respectively in the red band (0.580—0.680μm) are altered with growing stage and chlorophyll content. The reflectance is usually larger than transmittance in the red band. The reflectance is closed to transmittance in the near infrared band (0.725—1.100μm) which are changed with growing state and age of crop[12]. We also carried out the measurements and similar results were got with them. The reflective index of the leaf wax w_x and the leaf hair index f_x for wheat almost keep a constant. We adopted approximately $w_x = 1.35$, $f_x = 0.10$. The relative leaf size $l_L = dl/h$, h is the canopy height which is useful parameter if we want to estimate roughness of surface. The LAI distribution with the NIR and RR wavebands illuminated in Fig. 3 by using 2-set different initial inputs. The most sensitive initialinputs are reflectance and transmittance of individual leaf in the near infrared band. Fortunately, their changing range are not very large. So long as we have a database about the throughout growing, a set of adequate estimation of initial inputs could be got. Therefore the inverting algorithm is feasible.

3 FIELD MEASUREMENT AND RESULT OF THE INVERSION*

According to the existing database of wheat[13,14] and calibration by authorized department in 1992 for the spectrum radiometer the field measurements are reliable and usable for validating the inversion algorithm. The SE590 spectrum radiometer with 0.38—1.10μm spectrum responsive range and the lens of 1° and 15° FOV were adopted. To measure BRDF of crops well we designed a spacial measuring tool whose view zenith and azimuth can be controlled manually. BRDF measurement was in company with actual observation of optical properties and canopy structure parameters. For the reflectivity and transmissivity of individual leaf in the RR and NIR bands we adopted offered by Walter-shea and her colleagues (by communication in email). BRDF of the individual leaf exist, but nadir direction was measured by us only. The hair and wax index are referred to suggestion of Kuusk. The leaf area index is key parameter which is measured by means of the leaf-area-meter (produced by Licor company in USA). The leaf angle distribution and average leaf angle, height of canopy, width of leaf, length of leaf also are basic parameters which were measured carefully.

According to the sensitivity analysis and ground inversion results, we made decision to adopted n=2—3. but not n=10, and it is necessary to procure a set good data about four main factors from NOAA-AVHRR images before running the inversion algorithm. As addition to calibrate NOAA-AVHRR and compare between ground turth and inversion results using satellite data, the data of ground and satellite on the same day — May 3, 1993 was selected. On the day we carried out simultaneous measurement while NOAA satellite overpasses Yucheng Experimental Area where near by the Yellow River. There are three major ground surfaces: the wide river surface, the large sand land and the homogeneous wheat field. They all are bigger than actual area at 2 pixels of NOAA image. We utilized the three ground surface as calibrating targets of the lower, the middle and the high reflectance. Their multiangle reflectance can measured by means of SE590 spectrum-radiometer. About 200 reflectance readings measured only took us 10 minuets because of the fast speed of CCD sensors and potable computer. We can obtain representable data in the three targets. A correlated equation can be established using the representable reflectances of the three targets and corresponding digital greyness in the NOAA-AVHRR image looked up easily by a computer image processor. The correlated equation on May 3, 1993 can be written as:

$$RR_m = 0.000413 GN_{RRi} + 0.0012$$
$$NIR_m = 0.00236 GN_{NIRi} - 0.016 \quad (2)$$

where RR_m, NIR_m are reflectance of the three targets in the red and near infrared bands respectively, GN_{RRi}, GN_{NIRi} are corresponding digital greyness in the red and the near infrared bands respectively. The

* Dr. Andres Kunsk contributed the inversion code

correlated equation were established using the field reflectance measurements and corresponding digital greyness in the two bands. Then we can calculate reflectances at other points in the image according to the equations. In accordance with the method two reflectance distribution in the two band can be obtained. The calibration way is effective and feasible. The method is similar to the calibration of spectrum-radiometer and thermal infrared-radiometer in the laboratory using the integrating ball and the black-body source. It not only could calibrate reflectance of the images, but also may validate atmosphere correction model such as 5s or 6s model. So far there is no perfect atmosphere correction model. Obvious error could still be cause if a set standard atmosphere condition are adopted[15,16]. If a dataset of actual atmosphere condition are applied, the correction result could be improved. But we have to measure simultaneously the actual atmosphere condition whose troublesomeness may be more than or equivalent to the calibration way of canopy reflectance. For this reason we prefer to adopt the calibration of reflectance. Of course we should utilize the approximate model to do atmosphere correction if there is lack of the calibration condition.

The next step is to obtain view zenith and azimuth from image addition information that is usually issued by the agency of receiving the images. We can calculate the angles using some parameters and a formula. In terms of the strategy of n=2 we need to get an image angle information on May 03, 1993 only.

Finally, we adopted n = 2 inversion algorithm and import the 4 new images: the reflectance distribution of in the red and the near infrared bands and the zenith, azimuth distribution. LAI and ALA distribution images were proceed. see Fig. 4a. Fig 4b. In terms of Fig. 4a and Fig. 4b, we can see that the inversion algorism can give both LAI and ALA while n=2. And concrete values of the LAI and ALA were shown in the two output images. To validate the inversion result we selected three spots in the two output images and compared the calculated values with measured values as Table 1.

Fig. 4a Distribution of leaf area index

Fig. 4b Distribution of average leaf angle

Table 1 Comparison of inversion with measurements in the three spot samples

	LAI						ALA					
Spot type.	lake		wheat-1		wheat-2		lake		wheat-1		wheat-2	
Pixel position	x	y	x	y	x	y	x	y	x	y	x	y
	288	264	319	168	312	217	288	264	319	168	312	217
Inversion	0		4.32		4.87		0		58		56	
Measured	0.0		4.76		4.42		/		73		62	

The wheat-1 spot is located at the Yucheng Experiment Remote Sensing Site where pixel position is x=319 y=168. The wheat-2 spot is located at middle reflectance calibration target with homogeneous wheat. Comparison in the Table 3 shows good agreement between inverting and measuring results. The Dongping like is low reflectance calibration target whose leaf area index is equal to zero which maybe reasonable. Its average leaf angle is also equal to zero. We define roughly that the leaf angle without leaf area equals zero which is reasonable from nadir view. Analysis to distribution of LAI. from whole image indicated the souther-west part of the yellow river has the highest LAI where wheat growing condition is the best according to ground truth. The centre part of the image has middle LAI. The souther-east is the Tanshan montan without wheat. Its LAI is near to zero. The North-east is covered by cloud, so a unnormal situation emergent.

As well know, the relationship between NDVI and LAI as following formulary:

$$NDVI = 1 - e^{-(K_{AC} LAI)} \qquad (3)$$

where K_{AC} is coefficient which depends primarily on average leaf angle when crop is completely covered or depends on the average leaf angle and covering percent. Therefore NDVI can not separate LAI and ALA if ground calibration is carried not out.

As a result, although improvement is necessary for the inversion algorithm in future, it is worth to test and apply that in wider range.

4 CONCLUSION AND DISCUSSION

Through study of N-K inverting algorithm and inverting approach for wheat using NOAA-AVHRR images and ground surface measurements and calibration, we can summarize following:

1. N-K inversion algorithm is suitable for wheat canopy which covers completely. While wheat canopy has not covered completely, that is not homogeneous canopy, more obvious error could be caused.

2. The most sensitive parameter is the near infrared reflectance (NIR) in inversion of LAI. Practice experience suggested that optimum invertible condition exist for wheat canopy. Local time in observation ought to avoid principle plane at 12:00, principle plane at 10:00 and 14:00 have better inversion results. View zenith ought to avoid too low and too high degree. While the view zenith is close to the solar zenith, more precise inverting result can be got.

3. Order of parameters in the key array should be carefully allocated. Its order in the key array should be replaced if wheat height is inverted. S_R is background information.

4. Generally the soil reflectance and optical properties of individual leaf are treated as the initial input in the inversion algorithm. Even though n=10, those parameters still need initial guess. The test indicated that the reflectance and transmittance of individual leaf are the most important and sensitive parameters. To invert better result the two values must be determined very careful and exact. We deemed it is a disadvantage that the too sensitive initial input and can not be justified automatically to optimal value in the iteration.

5. In principle, the more n, the more the free parameters could be inverted. But in actual inversion using NOAA—AVHRR images, more number of reflectance values mean more images in different time or date. At present the best registration precision for NOAA—AVHRR only reaches 0.5 pixel, most cases are more than 1 pixel. Atmosphere correction still remain at approximate level. Therefore more n can cause more troublesomeness and error in the inversion. In addition, the sensitivity on some parameters may be low in certain situations, and inversion turns to more complicated with increasing number of free parameters. Possibilities to compensate each other by different parameters increase. Therefore n=10 may not work very well. When n=3 or n=4, the inverting results are better then n=2. In this case it seems overcoming the both disadvantages. Easy to realize n=3 or 4 in the ground surface measurement. It is also easier to obtain the 3 or 4 images at the same time and the same place if using MODIS or MIRS data in future. However at present, the case in n=3 or 4 will also meet registration and atmosphere correction. So we did comparison of number=2 with number=

or 3 or 4 or 10 and weighed the pros and cons in practice of the inversion. From spreading the inversion algorithm, we suggested number =2 is better. But we suggest adopted n > 3 after launching of MODIS MIRS.

6. Atmosphere correction is quite important process but is a trickiness problem in inversion of NOAA. A test of 5s and 6s algorithms indicated the obvious error still exist. In order to obtain usable data to application. For this reason, simultaneous measurement was carried out with NOAA — AVHRR when which was passing over the inverted region. The simultaneous measurements can be used for calibrating both NOAA-AVHRR image and atmosphere correction model.

7. NDVI is very popular in estimating biomass and the net primary productivity (NPP). So comparison of inversion result with NDVI could evaluate its significance in applications. There are two advantages to be obvious for using inversion of N-K model. 1) plant or crop structure parameters can be inverted directly without using correlation statistic method while the optical properties could be determined using ground surface calibration. 2) More than two parameters such as LAI, ALA can be obtained for n=2 inversion, whereas NDVI is just itself one parameters. 3) The bidirectional effect can be considered in the inversion algorithm, but can not for NDVI. As a result, although improvement is necessary for the inversion algorithm in future, it is worth to test and apply that in wider range.

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REFERENCES

[1] Suits, G. H. The calculation of the directional reflectance of vegetation canopy. *Remote Sen. Environ.*, 1972, **2**: 117—125.

[2] Ross, J. The Radiation Regime and Architecture of Plant Stands. Dr. W. Junk Publishers, The Hague, 1981.

[3] Goel, N. S., *et al*. Inversion of vegetation canopy reflectance models for estimating agronomic variables. *Remote Sens. Environ.*, 1983, **13**: 487—507.

[4] Verhoef. W. Light scattering by leaf layers with application to canopy reflectance modelling: the SAIL model. *Remote Sens. Environ.*, 1984, **16**: 125—142.

[5] Li, Xiaowen, Strahler, A. H. Geometric-Optical modelling of a conifer forest canopy. *A Trans. Geosci. Remote Sensing*, 1985, **23**: 207—221.

[6] Li, Xiaowen, Strahler, A. H. Geometric-Optical bidirectional reflectance modelling of the discrete crown vegetation canopy: effect of crown shape and mutual shadowing. *A Trans. geosci. Remote Sensing*, 1992, **30**(2): 276—292.

[7] Nilson T., Kuusk A. A reflectance model for the homogeneous plant canopy and its inversion. *Remote Sens. Environ.*, 1989, **27**: 157—167.

[8] Myneni, R. B., Ross, J. Photon-Vegetation Plant Interactions: Application in Optical Remote Sensing and Plant Ecology. Springer-Verlag, Heidelberg, 1991.

[9] Kuusk. A. A multispectral canopy reflectance model. *Remote Sens. Enviro.*, 1994, **50**: 75—82.

[10] Kuusk. A. A Fast, Invertible canopy reflectance model. *Remote Sens. Environ.*, 1995, **51**: 342—350.

[11] Goel, N. S., *et al*. Inversion of vegetation canopy reflectance models for estimating agronomic variables. *Remote Sens. Environ.*, 1984, **14**: 77—111, 1984, **15**, 223-236. 1984, **15**, 237—253.

[12] Walter-Shea, E.A., Norman, J. M. Leaf bidirectional reflectance and transmittance in corn and soybean. *Remote ens. Environ.*, 1989, **29**: 161—174.

[13] Zhang Renhua, Qin wenha. Collection of Bidirectional Reflectance Spectra of Maim Crops in North China. Science Press, 1991.

[14] Zhang Renhua. Experimental Remote Sensing and Ground base. Scientific Press, 1996.

[15] Kaufman, Y. J., Tanre, D. Atmospherically resistance vegetation index (ARVI)for EOS-MODIS. *A Trans. Geosci. Remote Sensing*, 1992, **30**: 260—270.

[16] Zhang, R. H. Rao, N. X., Liou K. N. Approach on vegetation index for resisting to atmosphere effect. *Botany Journal*, 1995, **48**.

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以 NOAA-AVHRR 数据及二向反射模型反演华北地区农田小麦的结构参数

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摘　要　以遥感手段对华北地区的小麦长势监测及产量预报，在部署农业持续发展的对策中起着十分重要的作用。最近十多年中，利用植被指数 NDVI 进行作物结构参数的估算非常普遍。由于 NDVI 和叶面积指数这一关键结构参数的定量关系存在着明显的不确定性，NDVI 已经不能满足更精确定量遥感的需要。

该文利用适宜均匀作物的 N-K 模型和 NOAA-AVHRR 影象图，在华北禹城周围 $500*500km^2$ 的面积内，对小麦的结构参数：叶面积指数，叶角分布或平均叶角等进行反演试验。

首先在禹城遥感试验场，以实测的小麦二向反射光谱数据及叶面积资料，分析 N-K 模型反演结果的灵敏度。对于红光波段与近红外波段的反射辐射相比较，叶面积指数的变化随近红外波段反射辐射的变化更敏感。待反演的 11 个参数与输入维数的差数就是初始输入值的维数。通常这些初始值已合理常显值表达。经试验表明，当输入维数较少时，初始值对反演结果有显著影响。

太阳角与观测角的组合是以热点附近为最佳选择。但实际的 NOAA-AVHRR 的观测角在华北平原变化并不大，对反演结果影响不十分明显。

该文最后阐明了地标同步观测对反演的作用。通过地面定标，输入了 4 幅以影象图格式的输入值，这些是观测天顶角分布，观测方位角分布，红光反射率分布，近红外反射率分布。根据反演算法一个一个象元进行计算。为压缩计算时间，采用了类似集群分析的图象处理方法。

结果表明，反演的叶面积指数和叶角分布是和地面实况相一致的。与 NDVI 相比较，确定性得到明显的提高。虽然进一步改进是必须的，但二向反射模型的反演有着广阔发展前景。

关键词　反演，叶面积指数，近似测量