遥 感 学 报
JOURNAL OF REMOTE SENSING

Process System of Measured Bidirectional Reflectance in Changchun Laboratory*

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Abstract Bidirectional reflectance measurement is very important in the BRDF model validation and inversion. For many reasons, there exists many errors in the measured data. As in the laboratory, there is no wind and cloud, thus the measured data is more stable than in vivo. These data have been used to validated and invert many BRDF models. A BRDF process system based on MS—Windows has been developed, which include measured bidirectional reflectance data management and preprocess, data 2D and 3D analysis, BRDF model validation, and model inversion. In this paper we chose four objects as test samples which are sparse dense cotton, cotton, soybean, and corn, to validate four empirical and semiempirical models which are Walthall, Roujean, Verstraete, Rahman model. The validated result fit measured data well.

We also used SAIL model to try our inversion test. At first, the parameter sensitivity and their distribution in view positions were analyzed, the according to analysis result we determined three cases: the most sensitivity area, the least sensitivity area and principal plane. Finally, the SAIL model parameters LAI, LAD, ρ, τ were inverted in three cases. The results show that: 1. The inversion of sensitive area is better than insensitive area. 2. The more sensitive model parameter is, the more precise and stable the inversion is. Therefore, whether a BRDF model model is invertable or not is not only depend on its mathematical invertibility, but also depend on what parameters you want to invert and what measured data you are using.

Key words Bidirectional reflectance measurement, Solar simulation laboratory, BRDF model inversion

1 INTRODUCTION

It is very important for BRDF research work and its application to obtain high quality bidirectional reflectance data sets. Those data sets may be used to validate the present varies BRDF model and to have inversion test. However, the collection of those bidirectional reflectance data is very difficult. There are only several data sets used in the world, and the measured ground cover biophysical parameters were not able to afford all model's demands. Changchun solar simulation laboratory provide us an opportunity to measure the bidirctional reflectance and canopy parameter. To compare with vivo data sets, It has several advantages: 1. The position of incident and detectors can be controlled manually. This make the repeat measurement become possible. 2. There is no cloud, so the effect of sky irradiance is small. 3. There is no wind, so the objects condition are more stable than in vivo.

The total BRDF measurement device is made up of simulated solar incident, remote sensed detector sets, object platform and automatic data collection device. The whole device was built in the black workshop.

2 BIDIRECTIONAL REFLECTANCE DATA PROCESS SYSTEM

Process system

The process system include four parts: 1. Data preprocess, which include data format converting, subset obtaining, background effect removing; 2. Bidirectional reflectance data analysis, which include

* This project is supported by the National Natural Science Foundation of China(49331020), partly by NASA EOS MODIS BRDF/Albedo project, ADEOS POLDER project and SPOT-4 VEGETATION project(95/CNES/0409)

2-D and 3-D graphics drawing and analysis; 3. BRDF model validation, which include SAIL model, Li-Strahler model, Ross' s model, Verstraete' s model, Roujean' s model, Walthall' s model and Rahman' s model[1-6]; 4. Model inversion, which include above model.

The system run on the MS-Windows. We use MS Excel as data manage tool, Winsurf as 3-D graphics tool and other parts of the system were compiled by Visual Basic language.

Effects analysis

In laboratory, the distance between detectors and view object is only 3 meters. In order to view the whole object(1m× 1m) , the view angle of detectors was designed as large as 8 degree. This will cause many effects, for example, the measured reflectance is not the real bidirectional reflectance because it is composted by many angle reflectance; the hot spot is not very obvious; the side of canopy will occurred in the view field when view zenith angle become large. In order to decrease the side effect we used the black cloth to round the side of canopy and the short vegetation were chose as test objects.

As the view zenith angle increase, the view field increase and the background effect increase. We will discuss this effect quantitative.

Suppose view zenith angle is θ, view field angle is ψ. The view field equation in nadir is:

$$x'^2 + y'^2 = (h - z')^2 \cdot tg^2\psi$$

Rotate θ angle around y axis, then we get the view field equation:

$$(\cos^2\theta - \sin^2\theta \cdot tg^2\psi) \cdot x^2 - 2h \cdot \sin\theta \cdot tg^2\psi \cdot x + y^2 = h^2 \cdot tg^2\psi$$

Fig. 1 demonstrate the change of the view field with the view zenith angle varies from 0 to 80 degree (h=3meters, φ= 8 degree)

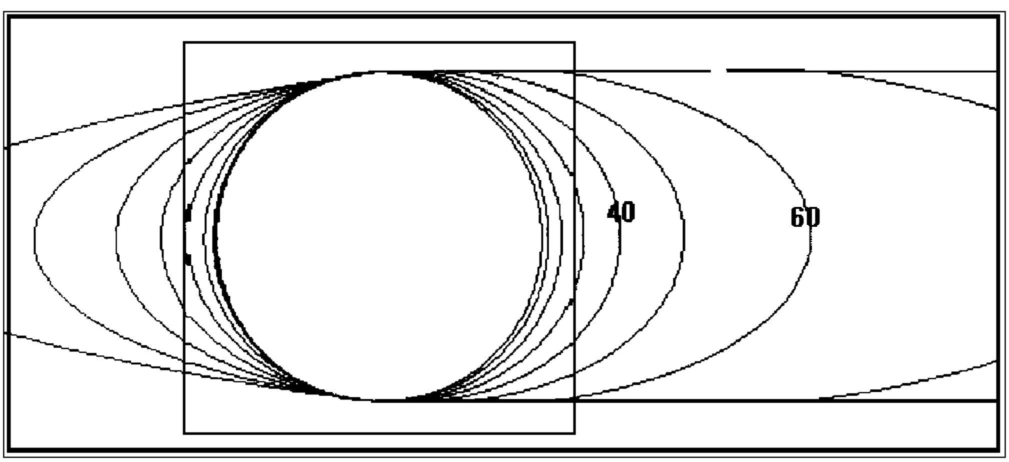

Fig. 1 View field change with different view zenith angle

Table 1 The ratio of valid field and invalid field

VZA	0	10	20	30	40	50	60	70	80
A2/ A1	0	0	0	0.006	0.061	0.204	0.547	1.526	12.027

Suppose A1 is a valid view field which will be viewed by detectors and A2 is invalid field. Table 1 show the ratio between A2 and A1.

The measured reflectance is:

$$R_m = \frac{(Q_O + Q_b)}{(Q_w + Q_b)} \tag{1}$$

where Q is radiant flux

o is object

w is white board

b is background

The background reflectance is

$$R_b = \frac{Q_b}{Q_w} = \frac{Q_b}{A_2/A_1 \cdot Q_w} \tag{2}$$

Use (1) and (2) the real reflectance is:

$$R_{real} = \frac{Q_o}{Q_w} = (1 + R_b \cdot \frac{A_2}{A_1}) \cdot R_m - R_b \cdot \frac{A_2}{A_1}$$

Where R_b can be obtained either from measurement or from deducing. Suppose we have a set of "standard directional reflectance" (such as grey board or soil). We establish an empirical Walthall BRDF model using subset data which view zenith varies from 0 to 30 degree. Then using these parameters we deduce the reflectance r^i_{real} which view zenith angle varies from 40 to 80 degree. Here the measured directional reflectance is r^i_m, then

$$R_b = \frac{\sum_{i=1}^{n}(r^i_{real} - r^i_m) \cdot X_i}{\sum_{i=1}^{n} X_i^2}$$

where

$$X_i = (r^i_m - 1) \cdot \left(\frac{A_2}{A_1}\right)_i$$

n is measured data number.

3 MODEL VALIDATION

For the Verstaete's model, Roujean's model, Walthall's model and Rahman's model, we first used measured data to invert model's parameters. Then we inferred bidirectional reflectance using forward model and compare with the measured data.

$$RMSE = \sqrt{\sum\{[(R_i - R_i')/R_i]^2/N\}}$$

Fig. 2 is four model validation result. The test object is sparse corn which incident zenith angle is 40 degree. Table 2 is four objects validation result.

Table 2 Four objects validation result

	NIR band				RED band			
MODEL	S-Cotton	Cotton	Soybean	Corn	S-Cotton	Cotton	Soybean	Corn
Walthall	0.127	0.119	0.230	0.199	0.202	0.198	0.214	0.218
Roujean	0.079	0.055	0.146	0.110	0.179	0.096	0.140	0.141
Verstraete	0.196	0.247	0.140	0.123	0.222	0.215	0.181	0.161
Rahman	0.104	0.102	0.160	0.117	0.164	0.159	0.157	0.153

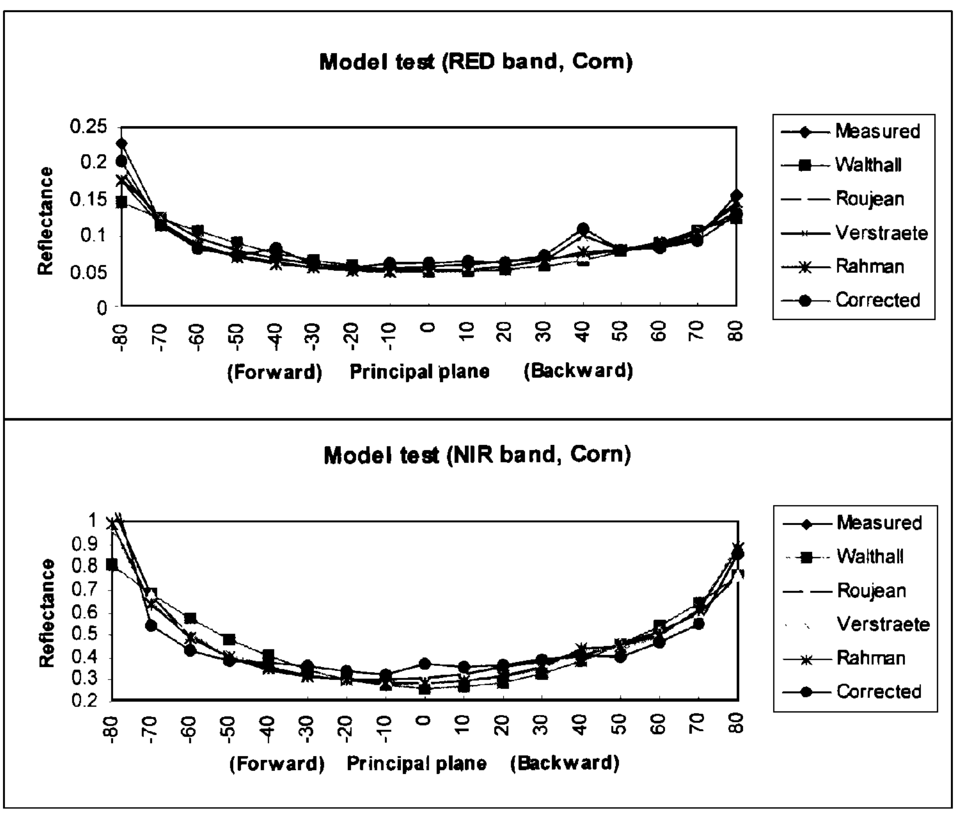

Fig. 2 Four model validation result (The test object is corn, SZA=40)

From table, one can see that empirical and semi-empirical BRDF models have ability to simulate measured data well. The maximum RMSE is less than 0.25. The results of NIR band are better than that of RED band. As LAI increase, the precise of Walthall and Roujean's model decrease in NIR band, while the precise of Verstraete's model increase. This may affect by the model's original suppose.

4 INVERSION TEST

Whether a BRDF model is invertiable or not is not only depend on the model itself but also on the measured data and what parameters you want to invert. Here we used SAIL model as an example to demonstrate the inversion process.

Inversion parameters analysis

Table 3 is the sensitivity of seven parameters in four bands using four samples. The sensitivity used here was defined as J. L. Privette *et al*.[7]. From table one can see: 1. The sensitivity of LAI in NIR band is higher than that in red, green and panchromatic band. Therefore it will be better to invert LAI use NIR band than other bands. 2. AS LAI increase, the sensitivity of LAI decrease and the sensitivity of leaf reflectance and leaf transmittance increase. So it is difficult to invert large LAI. We should have knowledge of leaf reflectance and transmittance before inverting large LAI. 3. As LAI increase, the sensitivity of soil decrease. So soil contribution may be neglected when LAI is large enough. 4. In laboratory, SKYL is not very sensitive. So we fixed it in the inversion. 5. The sensitivity of parameters are similar in all visible bands.

Table 3 Parameters sensitivity of four samples (sparse dense cotton, cotton, soybean, corn) in four bands (band 1: NIR, band 2: red, band 3: green, band 4: panchromatic)

COMMENTS	BAND	LAI	U	V	LR	LT	RS	SKYL
SPARSE COTTON	NIR	9.647	1.838	1.566	16.233	10.752	3.081	0.978
LAI=1.08	RED	4.676	0.678	0.709	14.171	2.652	5.044	0.628
ALA=23.86	GREEN	4.903	0.622	0.658	13.834	3.403	5.414	0.582
SZA=20	PAN	5.458	0.556	0.605	13.669	3.156	5.569	0.563
SPARSE COTTON	NIR	9.637	1.844	1.580	16.210	10.756	3.077	0.960
LAI=1.08	RED	4.675	0.762	0.779	14.160	2.678	5.037	0.902
ALA=23.86	GREEN	4.902	0.704	0.726	13.825	3.427	5.406	0.842
SZA=40	PAN	5.456	0.642	0.677	13.660	3.181	5.561	0.833
COTTON	NIR	8.476	1.576	1.277	17.995	19.119	1.123	0.599
LAI=2.16	RED	1.600	1.278	1.222	18.179	3.101	0.870	0.918
ALA=23.86	GREEN	1.803	1.235	1.181	17.996	3.999	1.006	0.858
SZA=20	PAN	1.994	1.221	1.172	17.989	3.702	1.026	0.862
COTTON	NIR	8.460	1.535	1.288	17.972	19.102	1.123	0.589
LAI=2.16	RED	1.598	1.361	1.296	18.157	3.137	0.867	1.188
ALA=23.86	GREEN	1.799	1.316	1.253	17.975	4.035	1.003	1.106
SZA=40	PAN	1.990	1.303	1.245	17.968	3.737	1.023	1.122
COTTON	NIR	6.246	1.432	1.110	19.621	24.403	0.320	0.282
LAI=4	RED	0.152	1.521	1.425	18.940	3.171	0.053	1.223
ALA=23.86	GREEN	0.174	1.504	1.405	18.851	4.067	0.070	1.116
SZA=40	PAN	0.187	1.508	1.410	18.877	3.760	0.067	1.150
COTTON	NIR	4.508	1.482	1.188	21.473	25.688	0.108	0.160
LAI=6	RED	0.052	1.511	1.413	18.959	3.165	0.031	1.196
ALA=23.86	GREEN	0.049	1.507	1.402	18.884	4.049	0.043	1.060

to be continue

COMMENTS	BAND	LAI	U	V	LR	LT	RS	SKYL
SZA=40	PAN	0.051	1.509	1.406	18.908	3.745	0.039	1.104
COTTON	NIR	3.309	1.604	1.310	23.342	25.722	0.052	0.107
LAI=8	RED	0.052	1.499	1.398	18.945	3.165	0.039	1.184
ALA=23.86	GREEN	0.046	1.507	1.396	18.878	4.039	0.054	1.017
SZA=40	PAN	0.047	1.505	1.397	18.899	3.739	0.049	1.070
SOYABEAN	NIR	5.379	4.871	4.584	25.595	43.392	0.913	1.069
LAI=4.47	RED	0.810	3.268	3.103	16.875	7.544	0.175	6.694
ALA=51.54	GREEN	0.584	4.116	3.964	17.865	6.800	0.171	4.342
SZA=20	PAN	0.808	3.529	3.354	17.113	7.663	0.202	5.780
SOYABEAN	NIR	4.992	3.527	3.553	24.973	42.337	0.771	0.831
LAI=4.47	RED	0.654	2.635	2.631	16.132	7.696	0.137	5.604
ALA=51.54	GREEN	0.483	3.024	3.138	17.252	7.047	0.140	4.197
SZA=40	PAN	0.658	2.696	2.722	16.409	7.836	0.161	4.949
CORN	NIR	0.332	1.981	0.864	20.163	26.137	0.178	0.483
LAI=7.07	RED	0.147	2.142	0.856	17.348	5.767	0.054	2.161
ALA=40.45	GREEN	0.130	2.071	0.848	17.407	7.802	0.085	1.592
SZA=40	PAN	0.141	2.062	0.848	17.247	6.904	0.070	1.859

Sensitivity area analysis

The sensitivity of parameter is differ with the view position. Fig. 3 is the sensitivity distribution of seven soybean parameters in NIR band (incident zenith angle is 40 degree). The darker the color is, the more sensitive the parameter is. From figure, one can see LAI, μ, υ, and ρ are more sensitive in forward direction, while ρs is more sensitive in backward direction, and τ is more sensitive in higher view zenith angle. The sensitivity distribution will change with the different objects and different incident position and different bands.

Inversion test

We chose four objects which are sparse dense cotton, cotton, soybean, corn. After analyzed the parameters sensitivity and their distribution, we divided view position as most sensitive area, least sensitive aea, and principal plane area.

Table 4 Inversion result of LAI

	Sparse dense cotton	Cotton	Soybean	Corn
Most sensitivity area	1.19	2.26	4.50	8.57
Principal plane	1.23	2.43	4.59	5.19
Least sensitivity area	1.07	1.92	3.59	4.64
Measured LAI	1.14	2.16	4.47	7.70

Table 4 is the inversion result. The inversion result using sensitive area data is more accurate than other two data sets. As LAI increase, the inversion become very unstable, especially when leaf reflectance or transimittance has a subtle change. This is because the sensitivity of leaf reflectance and transimittance are much large than that of LAI. Therefore, We must carefully determine the ρ and τ first, and keep it a little change during inversion when inverting large LAI canopy.

5 CONCLUSION

The laboratory bidirectional reflectance data have been used to validate and invert many BRDF models. A BRDF process system based on MS-WINDOWS has been developed, which include measured bidirectional reflectance data management and preprocess, data 2D and 3D analysis, BRDF model validation, and model inversion. We chose four objects as test samples, which are sparse dense cotton, cotton, soybean and corn, to validate four empirical and semiempirical models which are Walthall, Roujean, Vertraete, Rahman model. The validated result fit measured data well.

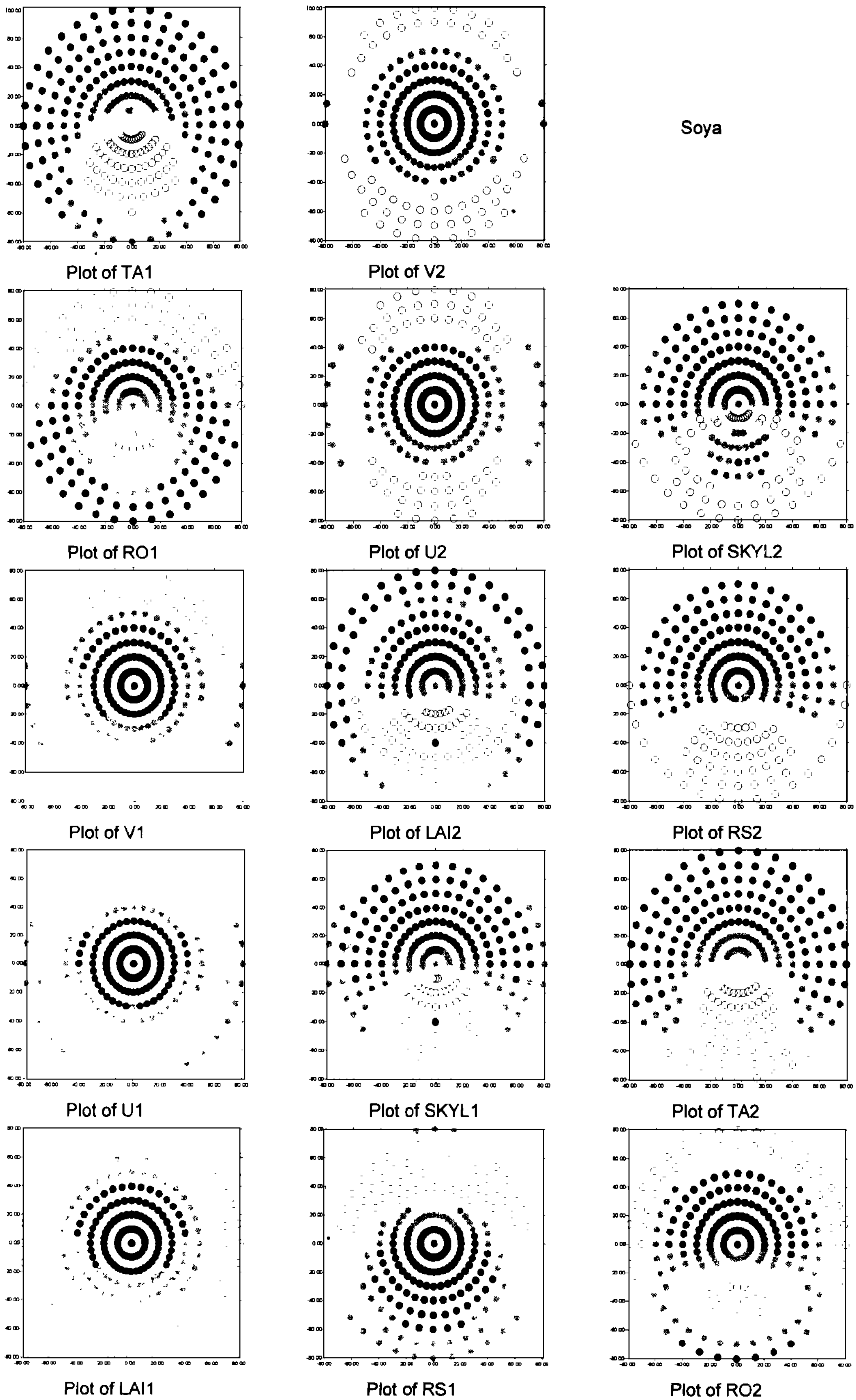

Fig. 3 Parameters sensitivity distribution of soybean in NIR band 1 and RED band 2.(SZA=40)

We also used SAIL model to try our inversion test. At first, the parameter sensitivity and their distribution in view positions were analyzed, then according to analysis result we determined three cases: the most sensitivity area, the least sensitivity area and principal plane. Finally, the SAIL model parameters LAI, LAD, ρ, τ were inverted in three cases. The results show that: 1. The inversion of sensitive area is better than insensitive area. 2. The more sensitive model parameter is, the more precise and stable the inversion is. Therefore, whether a BRDF model is invertible or not is not only depend on its mathematical invertibility, but also depend on what parameters you want to invert and what measured data you are using. Beside this, knowledge supporting is also very important in inversion process[8].

Of course, laboratory measurement has some defects, such as view field range is too small, and detectors, view angle is too large.

ACKNOWLEDGMENT

The bidirectional reflectance data were collected in Changchun solar simulation laboratory. Engineer Jin Xifeng's assistance is appreciated. The canopy parameter were measured by Zhang Hong, Zhao Liping and Sun Rui. Their contribution are gratefully acknowledged.

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AUTHOR

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BRDF 室内实验处理系统及应用

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摘 要 与野外 BRDF 实验相比，室内实验更容易控制，具有无风、无云、光源固定和可全方位重复观测等优点，获取的反射率数据和测量的植被结构数据的精度要较野外测量的高，可用于 BRDF 模型验证及反演试验。

BRDF 室内实验处理系统是专门针对 BRDF 实验数据的处理而设计的，它具有数据处理、分析、模型验证、模型反演的功能。系统建立在 MS Windows 之上，使用 Visual Basic 和 C 语言作为编程语言并使用 Winsurf 作为三维分析绘图工具。数据预处理部分包括背景影响校正，反射率数据转换，子集数据选取；数据分析部分包括二维、三维图形绘制与打印，数据集比较；BRDF 正向模型验证部分包括 SAIL 模型、Roujean 模型、Walthall 模型、Li-Satrahler 模型、Verstraete 模型、Rahman 模型。模型反演部分包括 SAIL 模型、Roujean 模型、Walthall 模型、Verstraete 模型、Rahman 模型的反演。

文中用 BRDF 室内实测数据（稀疏棉花、棉花、大豆、玉米）对 Walthall，Roujean，Verstraete，Rahman4 种模型进行了验证。结果表明这些经验或半经验二向性反射模型的计算结果与不同目标的测量值均较好吻合，最大 RMSE 小于 0．25，近红外波段的拟和结果优于红光波段，随 LAI 的增加，Walthall 和 Roujean 模型的精度降低，而 Verstraete 模型的精度增加，这与各模型的基本假设有关，Walthall 模型最初是为土壤 BRDF 模型而设计的，Roujean 模型中几何体影响以长方体表示的且各自阴影互不重叠，因此这两种模型较适合稀疏植被，而 Verstraete 模型是均匀植被模型，因此更适合密集植被的情况。

该文还用 SAIL 模型进行了反演试验。首先计算了 SAIL 模型各参数的敏感性以及各参数在不同观测位置的敏感性分布。根据这种敏感性分布，我们将测量数据分为最敏感区域、最不敏感区域、主平面区域。对这 3 种情况分别反演叶面积指数 LAI，叶倾角分布 LAD。结果如下表所示。

	稀疏棉花	棉花	大豆	玉米
最敏感区数据	1．19	2．26	4．5	8．57
主平面数据	1．23	2．43	4．59	5．19
最不敏感数据	1．07	1．92	3．59	4．64
测量 LAI 数据	1．14	2．16	4．47	7．70

结果表明：1. 敏感区数据的反演结果要优于非敏感区的反演结果。2. 模型中参数越敏感，反演的结果越精确、稳定。因此一个模型是否能反演不仅与模型本身有关，还与所要反演的目标以及反演中使用的测量数据有关。

关键词 二向反射测量，太阳模拟实验室，BRDF 模型反演