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The non-Lambertian Problem in the Dynamic Minitoring of Vegetation by NOAA-AVHRR

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Abstract At present NOAA-AVHRR can offer us many multi-angle earth observation data. through careful collection of successive AVHRR images, the existence of non-Lambertian effect had been proven. Its relative variance will not be larger than 30%. It is not surprising large, but it can not be neglected too. This paper reports an initial study about how to correct the non-Lambertian effect through building up BRDF models for vegetation and soil background and with the help of decomposing method of mixed pixel. Results show our method is basically correct and practical. Further study is still needed because of the effect of non-Lambertian mixed with other problems, such as atmospheric correction.

Key words Non-Lambertian effect, BRDF models, Decomposing method of mixed pixel

1 INTRODUCTION

We can get vegetative information of earth surface almost every day from NOAA-AVHRR data, therefore many people try hard to carry out the dynamic monitoring of vegetation by them. However, it is not a easy job, because the data of channel one and two of AVHRR own obvious non-Lambertian property, since the scanning angle of sensor is so wide (± 55°) and the orbit of its nadir point drifts with a period of 9.5 days.

Once we collected NOAA-AVHRR data of Northern China in successive 12 days without cloudy cover. After geometric correction all images overlay together. Signals along a common line were shown in Fig. 1.

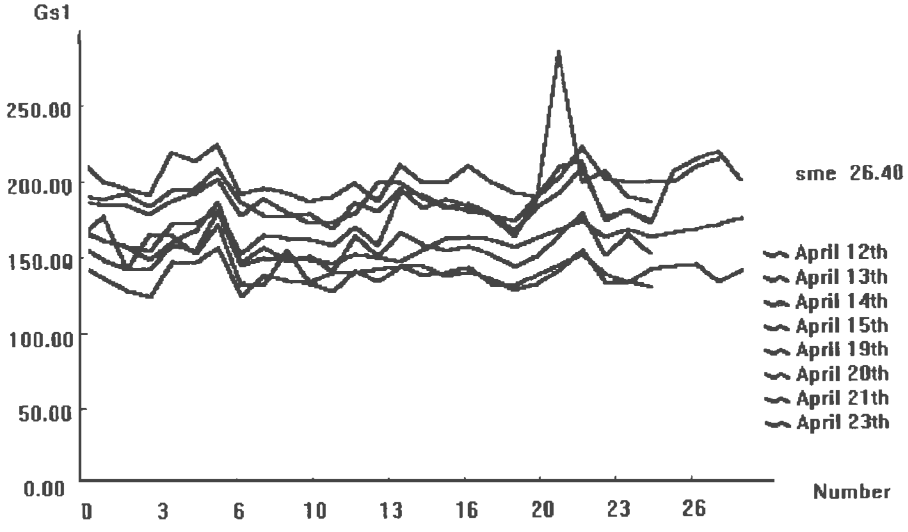

Fig. 1 The fluctuation of signals along a common line, CHI

They are quite different, in another words, for the same place signals fluctuate day after day, its relative variance can reach 30% sometimes.

This phenomenon had also been reported by different authors[1,2] from various view angle. Of course, vegetation can' t change so quickly in such short time. The reasons of fluctuation may come from:

(1) The non-Lambertian characteristics of targets which at least includes vegetation and bare soil background now.

(2) The effect of atmosphere which owns non-Lambertian features too.

(3) The different size of pixel for different viewing angle.

All these problems are mixed together which makes correction more complicated than usual case, for the moment we put second and third problems aside, in order to concentrate our attention on the first question.

Suppose the mixed pixel only consists of winter wheat and bare soil backgound. The $(\mathrm{BRDF})_m$ of mixed pixel can be calculated by linear adding method weighted by their area ratio.

$$(\mathrm{BRDF})_m = A_w(\mathrm{BRDF})_w + (1 - A_w)(\mathrm{BRDF})_s \quad (1)$$

The subscript m, w and s means "mixed", "wheat" and "soil" respectively. A_w represents area ratio of winter wheat within mixed pixel. Since $(\mathrm{BRDF})_w$ and $(\mathrm{BRDF})_s$ have their own characteristics, so at first we have to establish a different model for $(\mathrm{BRDF})_w$ and $(\mathrm{BRDF})_s$ respectively, then we can find a proper way to correct non-Lambertian effect.

2 THE GEOMETRI—COPTICAL MODEL OF (BRDF)S

Based on experimental data G.L.Walthall[3] *et. al*. offered a simple formula of reflectance of soil-vegetation system. For bare soil surface it takes form:

$$R_s = \frac{R_{H,S}}{0.1S}[A\vartheta_v^2 + B\vartheta_v\cos(\phi_v - \phi_s) + C] \quad (2)$$

Where $R_{H,S}$ is the hemisphere reflectance of soil, ϑ_v, ϑ_s are viewing and solar zenith angle, ϕ_v, ϕ_s, are viewing and solar azimuthal angle respectively. A, B, C are parameters depending on ϑ_s.

$$A = -4.988\times 10^{-4} - 2.953\times 10^{-5}\vartheta_s + 8.920\times 10^{-7}\vartheta_s^2$$

$$B = 6.988\times 10^{-4} + 2.243\times 10^{-3}\vartheta_s$$

$$C = 14.46 + 3.216\times 10^{-2}\vartheta_s - 1.7373\times 10^{-3}\vartheta_s^2$$

We did not adopt this formula for $(\mathrm{BRDF})_s$ correction, because the shadow casted by protrusion is one of the main reason for non-Lambertian property of soil surface, but parameter of roughness does not appear in Walthall' s formula.

J.Cierniewski[4,5] had offered a good geometric-optical model of reflectance of soil surface. Since it contains too many unknowns, it is still inconvenient to use, so we want to form a simple but accurate enough model.

Since the pixel size of AVHRR is so large and the Northern China plane is so flat that the effect of micro-geomorphology can be neglected, therefore only four parameters are kept in our model, they are viewing and solar zenith angle $(\vartheta_v, \vartheta_s)$, relative azimuthal angle $(\phi = \phi_v - \phi_s)$ and roughness of surface (RFm). We suppose the effect of roughness can be modeled by balls, r represents the average radius of balls, d represents the average distance between balls, so the roughness RFm can be defined by

$$\mathrm{RFm} = \frac{r}{d} \quad (3)$$

Shadow area (S_a) can be calculated by geometric-optical principle if we know $\vartheta_s, \vartheta_v, \phi$ and RFm.

The shadow coefficient (SCm) can be defined by

$$\mathrm{SCm} = \frac{S_a}{d^2} \quad (4)$$

SCm is a function of four variables ($\vartheta_s, \vartheta_v, \phi$ and RFm). It is very difficult to express the relationship between SCm and four variables by analytical function, but we can make a SCm table for practical use. Let

$$\beta_\lambda = \frac{I_\lambda(\vartheta_v, \vartheta_s, \phi, \mathrm{RFm})}{I_\lambda^0(\vartheta_v = \vartheta_s, \phi = 0)} \quad (5)$$

Where I_λ^0 is the radiance received by sensor at hot spot which means at this position no shadow can be seen by sensor. I_λ is the radiance received by sensor at any position and roughness values. The β_λ is called attenuation coefficient. For this moment we use exponential function to link β_λ and SCm.

$$\beta_\lambda = a \exp(bSCm) \qquad (6)$$

Where a, b are constant to be fixed by experimental data now. a= 0.979, b=−1.261 were chosen for channel one, a= 0.977, b=−1.089 were chosen for channel two.

Of course, we can know values of ϑ_v, ϕ_v and ϑ_s, ϕ_s from NOAA data or calculated by astronomical formula, but we have to estimate RFm from images themselves during the period from Nov. to Feb., because this time the vegetative cover in Northern China can be omitted. We had collected seven images of our test area, for every pixel we calculated ϑ_v and ϑ_s and ϕ, the value of radiance already known, then the relative variance of radiance can be known too. Suppose a RFD value, then SCm And I_λ^0 can be calculated through SCm table and formula (5) and (6). If one of RFm values makes the relative variance of I_λ^0 to be the lowest one, then we consider it as the best choice of RFm value. Table 1. shows an example.

Table 1 The choice of RFm value

date	ϑ_s	ϕ	ϑ_v	I_λ	RFm	I^0
1993. 10. 15	75. 47	-15. 75	38. 88	142. 00	0. 29	208. 69
1993. 10. 18	70. 00	162. 68	-4. 70	77. 00	0. 29	139. 08
1993. 10. 19	68. 13	162. 05	-20. 98	84. 00	0. 29	140. 39
1993. 10. 23	78. 07	-17. 15	40. 23	147. 00	0. 29	213. 37
1993. 11. 02	76. 95	-19. 31	17. 14	98. 00	0. 29	167. 24
1993. 11. 03	75. 00	-19. 85	0. 05	104. 00	0. 29	191. 22
1993. 12. 22	82. 00	152. 72	-3. 46	113. 00	0. 29	205. 11

relative variance before correction 39. 9%, relative variance after correction 23. 6%.

Results show in our test area the RFm value varies from 0. 24 to 0.29.

3 THE MODEL OF $(\mathrm{BRDF})_\omega$

Since the pass time of satellite is relatively fixed, its variation is so limited that the relative azimuthal angle varies in certain range, for example, ϕ changes within $-15^\circ - -20^\circ$, $15^\circ - 20^\circ$, $160^\circ - 165^\circ$ for Northern China (NOAA-14), so it is impossible to observe hot spot phenomenon by NOAA-system, therefore we do not require the vegetative model to describe hot-spot behavior very well, but for other part.

The Walthall' s vegetative model is just fit our demand. It is a simple one, the results of least-squares fitting with experimental data show RMS $\leq$ 0.2 for channel one RMS$<$3 for channel two, except hot spot region. It takes form:

$$R_v = a\vartheta_v^2 + b\vartheta_v\cos(\phi_v - \phi_s) + C \qquad (7)$$

a, b, c are experimental constants, they change with ϑ_s and LAI. So, this formula has four inputs, ϑ_s, ϑ_v, ϕ and LAI.

Of course, we can not know real value of LAI for every pixel, but we can know its average value $\overline{\mathrm{LAI}(t)}$ through field measurements, we use $\overline{\mathrm{LAI}(t)}$ instead of in order to carry out non-Lambertian correction of $(\mathrm{BRDF})_w$

4 THE REITERATION

If we use formula (1) to carry out non-Lambertian correction of mixed pixel, then we have to know A_w in advance. How to solve this problem ? We pray for help from so called " Decomposing method of mixed pixel"[6].

The principle of this method is very simple. The area ratio of any element within mixed pixel can not change with time, but their reflectance must be variable, through field measurements PVI value of winter wheat, rape seeds, bare soil and water body change with time in different way. Fig. 2. shows the results.

If we have collected multi-time images of the same area, then we can use principal analysis method to know area ratio for every element within one mixed pixel.

Since the existence of non-Lambertian effect, the PVI value calculated from satellite data can not change so smoothly with time. They will show up and down if compared with true value, but experimental data (Fig. 1) had told us that the deviation will not exceed 30%, that means the main information of PVI is right, so the reiteration will help us to find a correct answer.

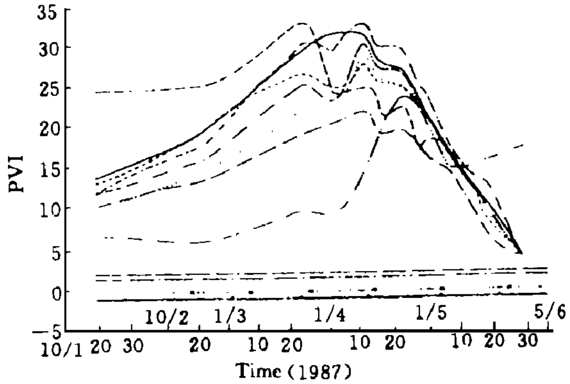

Fig.2 Changes of PVI values of different targets with time

(1) Using original radiance data to know A_ω with the help of decomposing method of mixed pixel.

(2) Using models of $(BRDF)_w$, $(BRDF)_s$ and formula (1) to do non-Lambertian correction then to get a new I_λ^0 data of mixed pixel.

(3) Using new I_λ^0 data to calculate PVI value again, and then run "decomposing method" program again to get a new value of A_w'.

Repeat (1)→(3) until $A_w' - A_w < \varepsilon$ which is a small number set before.

5 RESULTS AND DISCUSSION

Fig. 3 show us the fluctuation of reflectance data after correction.

Generally speaking, the relative variance of reflectance is reduced from about 30% to 10%—15%. It is reasonable, because we had omitted two other factors. Up to now we can not correct non-Lambertion effect on the pixel base, because it is impossible to know LAI and A_w exactly in advance on pixel size. So our experiments only offer a method for non-Lambertian correction with statistical meaning. Further studies are needed.

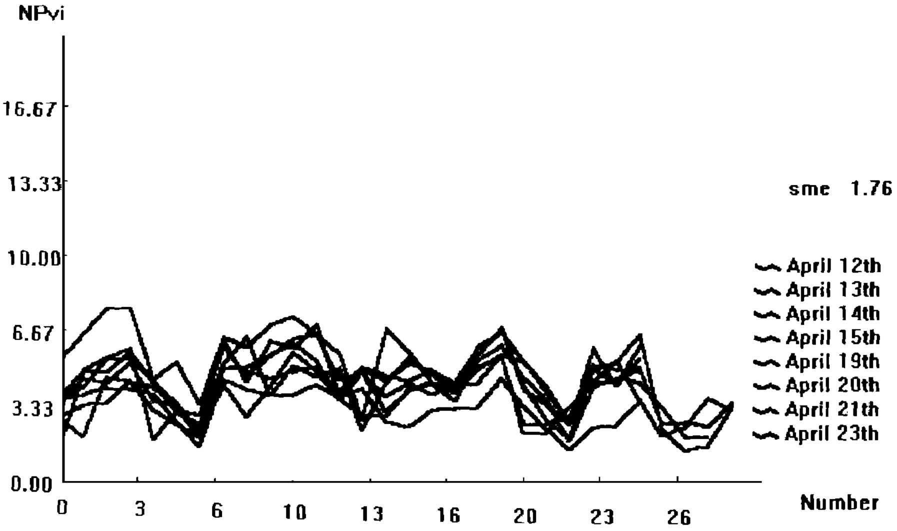

Fig. 3 The fluctuation of reflectance after correction

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NOAA-AVHRR 在植被动态监测中的非朗伯体问题

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摘　要　当今NOAA-AVHRR能提供许多多角度的对地观察资料。它的非朗伯体效应已经被细心收集的连续的AVHRR图象所证实。它的相对方差值不大于30%。这既不大得令人惊奇，但它亦不可能被忽视。该文提供了一个初步的研究报告，关于在混合象元分解方法，植被和土壤的BRDF模型基础上如何纠正非朗伯体效应的初步结果。结果表明我们的方法基本上是正确的并且是可行的。由于非朗伯体效应与其他问题，比如大气效应，纠缠在一起，所以进一步的研究仍然是必要的。

关键词　非朗伯体效应，BRDF模型，混合象元分解