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: 2008-06-12; : 2008-10-22
(: 10501051, 10871191) (: 2007CB714400, 2005CB422104)

(BRDF) . BRDF
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, BRDF
, . BRDF
(Roujean , 1992): $f_{iso}+k_{vol}(t_i, t_v,)f_{vol}+k_{geo}(t_i, t_v,)f_{geo}=r(t_i, t_v,)$, r
; k_{vol} k_{geo} , ,
( ); t_i , t_v ; -
; f_{iso}, f_{vol} f_{geo} , .
/ . ,
. BRDF .
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( ) (
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(2001) . Pokrovsky
(2002) QR BRDF . Wang (2007)
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, . (Wang , 2007),
l^1 .
, .

, (bidirectional reflectance distribution function, BRDF)

[1]. ,

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:

$$y=h(x, S), \quad (1)$$

y , x

, S , h x S

, .

, S , :

$$D=h(x, S)+n, \quad (2)$$

D $\mathbb{R}^M$, M

M M

, n $\mathbb{R}^M$ M .

m . , $M=m$, (2)

,

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, $M>m$, (2) [2].

, . ,

, (Least Squares Solution with Minimum Norm). [3]

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. [5, 6] , QR BRDF

. [7] ,

(NTSVD).

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":=" " "; " x " ,

; "argmax" " "; "max" "min" " " " " ; "diag()" ; "A^T" A ; "s.t." " " .

1 BRDF

1.1 BRDF

, (2) .

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[8]. , BRDF . [1]:

$$f_{iso} \quad k_{vol}(t_i,t_v, \ ) f_{vol} \quad k_{geo}(t_i,t_v, \ ) f_{geo} \quad r(t_i,t_v, \ ), \quad (3)$$

r ; k_{vol} g_{geo} ,

,

( ); t_i ; t_v ; -

Æ ; f_{iso}, f_{vol} f_{geo} ŭ , Л . , BRDF а . , RossThick (k_{vol}) LiSparse (k_{geo}) Л BRDF Л BRDF . k_{vol} Roujean [1] , ŭ RossThick , è У ŭ

$$k_{vol}(t_i,t_v,\ ) \quad \frac{1}{\cos t_i \quad \cos t_v} \quad \frac{\pi}{2} \quad \cos \quad \sin \quad \frac{\pi}{4}. \tag{4}$$

t_i=t_v=0 , Ю

$$\cos \quad \cos t_i \cos t_v \quad \sin t_i \sin t_v \cos \tag{5}$$

. ˜Ω ¥ ˝I k_{geo} LiSparse , ŭ

$$k_{geo}(t_i,t_v,\ ) \quad O(t_i,t_v,\ ) \quad (\sec t_i \quad \sec t_v)$$

$$\frac{1}{2}(1 \quad \cos \quad)\sec t_v , \tag{6}$$

$$O(t_i,t_v,\ ) \quad \frac{1}{\pi}(t \quad \sin t \cos t)(\sec t_i \quad \sec t_v),$$

$$\cos t \quad \frac{h}{b}\frac{\sqrt{D^2 \quad (\tan t_i \ \tan t_v \ \sin \ )^2}}{\sec t_i \quad \sec t_v},$$

$$D \quad \sqrt{\tan^2 t_i \quad \tan^2 t_v \quad 2\tan t_i \ \tan t_v \cos \ },$$

$$\cos \quad \cos t_i \ \cos t_v \quad \sin t_i \ \sin t_v \cos \ ,$$

$$\tan^{\ 1} \ \frac{b}{r}\tan \quad ,$$

t_i t_v, h, b, r .

LiSparse а . ŭ Ю, ŭ LiSparse $\exp(x)$ 1 x а [9], ŭ . ŭ , LiSparse (LiSparseR), ↓ ? (6),

$$k_{geo}(t_i,t_v,\ ) \quad O(t_i,t_v,\ ) \quad (\sec t_i \quad \sec t_v)$$

$$\frac{1}{2}(1 \quad \cos \quad)\sec t_i \ \sec t_v . \tag{7}$$

LiSparseR Ў а . , GO , LiTransit :

$$k_{\text{Transit}} \quad \begin{cases} k_{\text{Sparse}}, B \ \text{Ů} \ 2, \\ \frac{2}{B}k_{\text{Sparse}}, B \quad 2, \end{cases} \tag{8}$$

è B Ю B: $B(t_i,t_v,\ )$ $O(t_i,t_v,\ )$ $\sec t_i$ $\sec t_v$. RossThick LiTransit ŭ ↓ , ŭ Э , ч .

1.2

(3) ,

:

$$Kx=y, \tag{9}$$

x $[f_{iso}, f_{vol}, f_{geo}]^T$ y $[y_j]$, è y_j $r_j(t_i,t_v,\ )$, y ? .

y x.

а ╠ BRDF , ш а , ˜ΩЛ . , Л ( ) (а ¥).

а , , Л .

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ŭ а ╠ , ά ˝I . Y :

$$\min J(x), \tag{10}$$

$$\text{s.t. } Kx=y, \tag{11}$$

$$_1 \ \text{Ů} \ c(x) \ \text{Ů} \ _2, \tag{12}$$

è $J(x)$, ŭ x , $c(x)$ x , ŭ ˚ $c(x)$. , $J(x)$ ↓ а Ю x . x ↓ , ↓ $J(x)$ ŭ ˝I , ↓ $J(x)$ ŭ ˝I .

$c(x)$ ฏ ˝l ฏ ˝l .

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Li [4] ˝l ,

¥ C_p , C_p

x ˝l .

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Э [11~13]. Υ Э, ฏ ¥ ˝l

¥ у [7], ¥

γ ,

$$J(x) = \|Kx - y\|_{l^2}^2 + \|Dx\|_{l^2}^2 \quad (13)$$

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$J(x)$ у a

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2.2.2 (NTSVD)

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. Pokrovsky [5] QR

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a . Wang [7]

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у (NTSVD).

K й

$$K = U \Sigma V^T = \sum_{i=1}^{N} \sigma_i u_i v_i^T ,$$

ὲ $U=[u_i]$ $V=[v_i]$ й у , U

ฏ V й ;

й ὲ K .

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(NTSVD), Ю:

$$x^{\mathrm{NTSVD}} = \sum_{i=1}^{\tilde{p}} \frac{1}{\sigma_i}(u_i^T y)v_i , \quad (14)$$

$\tilde{p}$ [7]. Υ Э, NTSVD

(10)~(12) ,

$J(x) = 1/2\|Kx - y\|_{l^2}^2$ ฏ $c(x)$ x (,) .

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NTSVD . ¥ ฏ

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2.2.3 l^1

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(LAI), Lambertian ,

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x^* l^1

$$\min_x \|x\|_{l^1}, \quad (15a)$$

$$\text{s.t.}\ Kx=y, \quad (15b)$$

$$x \geq 0, \quad (15c)$$

l^1

l^1

(15) [14,15]

(A).

l^1

$$S = \{x : Kx = y,\ x \geq 0\}.$$

S

(15)

$$\max\ y^T g, \quad (16)$$

$$\text{s.t.}\ s = e - K^T g \geq 0, \quad (17)$$

e 1.

$(x,\ g,\ s)$

$$Kx = y, \quad (18)$$

$$K^T g + s = e, \quad (19)$$

$$\tilde{S}\tilde{F}e = 0, \quad (20)$$

$$x \geq 0,\ s \geq 0, \quad (21)$$

$$\tilde{S} = \mathrm{diag}(s_1, s_2, \cdots, s_N),$$

$$\tilde{F} = \mathrm{diag}(x_1, x_2, \cdots, x_N),$$

$s_i,\ x_i$ s x $\mathrm{diag}(\cdot)$

$\{x_k, g_k, s_k\}$, $x_k>0$ $s_k>0$. k

$\|y - Kx\|$ $\|K^T g_k + s_k - e\|$ $x_k^T s_k$

A.

2.2.4

(10)~(12)

BRDF

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73 [4]. 73 BRDF

18 BRDF

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( ) NTSVD

1 LAI

		LAI
kimes.irrwheat		4
kimes.hardwood	Л	4.2
kimes.soy		4.6
kimes.corn		0.65
kimes.orchgrass		1

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NTSVD ˝l (VisRed)
(Nir)
2, 3 Љ l^1 ˝l (VisRed)
(Nir)
4 5. 2 , WSAs
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, l^1 NTSVD й
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[16] .
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2 NTSVD WSAs б
WSAs ˝l (VisRed)

	0.060975284	0.077371794
Л	0.030110122	0.036017748
	0.055554622	0.066419290
	0.108295684	0.078334436
	0.031414520	0.037576732

3 NTSVD WSAs б
WSAs (Nir)

	0.239921484	0.288654970
Л	0.252075923	0.369430037
	0.364501461	0.513398848
	0.389020678	0.296322714
	0.283347191	0.515229716

4 l^1 WSAs б
WSAs ˝l (VisRed)

	0.101101803	0.077371794
Л	0.039901819	0.036017748
	0.050401846	0.066419290
	0.057701894	0.078334436
	0.028101856	0.037576732

5 l^1 WSAs б
WSAs (Nir)

	0.272701813	0.288654970
Л	0.263901792	0.369430037
	0.497901847	0.513398848
	0.280401851	0.296322714
	0.520901852	0.515229716

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(MODIS)1B й BRDF
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1B , NTSVD Љ ﻫ ɣ l^1
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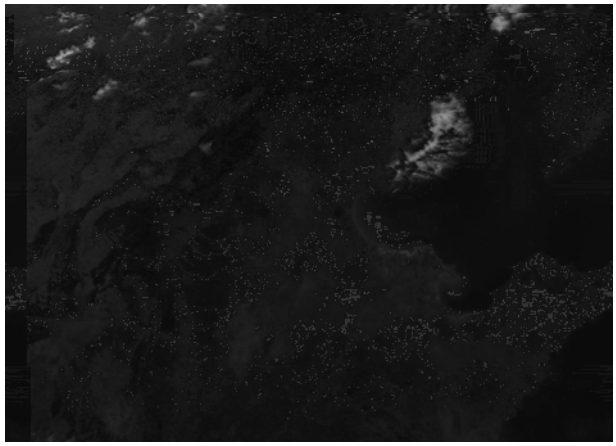

في 1 MOD021KM.A2001137 1 BRDF

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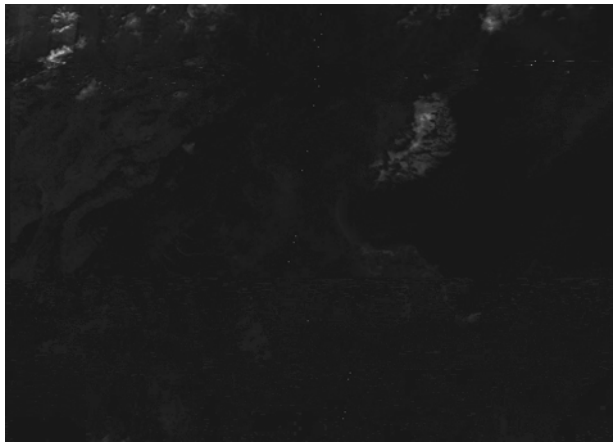

في 2 NTSVD

MOD021KM.A2001137 1

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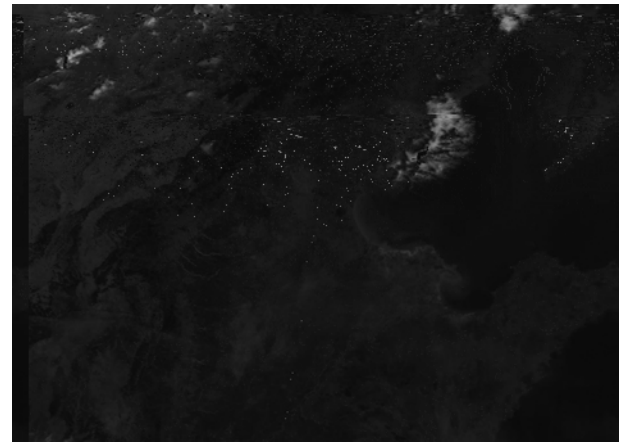

في 3 ⎓ ¥ l^1

MOD021KM.A2001137 1

$$J(x) \quad \|Kx \quad y_n\|_{l^2}^2 \quad \|Dx\|_{l^2}^2 \qquad (22)$$

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(22) ٧ (10) .

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K . (22) l^p

(p>0, $p \neq 2$), ¥ l^p ע .

Tikhonov ע

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[7]). ¥ MODIS,

¥ è æ , ٭ ⎓ ¥ l^1

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BRDF ╟ Л∪ ″l ,

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. 3.3

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$$\min e^T x, \text{ s.t. } Kx=y,\ x ů 0, \quad (A.1)$$

ɛ̀ x й N ɺ , ɛ̀ x_i , i=1, 2, …, N. (A.1) Љ

$$\max y^T z, \text{ s.t. } K^T z \quad s \quad e,\ s ů 0, \quad (A.2)$$

Э , ῶ ɣ

ᇔ [14, 15]. й

, у Log

$$\min e^T x \quad \sum_{j\ 1}^{N} \log(x_j),\ s.t.\ Kx \quad y,\ x ů 0. \quad (A.3)$$

ɛ̀

$$\lim_{x_j} \quad \log(x_j) \quad . \quad (A.4)$$

x>0, x>0. Ю ɣ

$$L(x,z) \quad e^T x \quad \sum_{j\ 1}^{N} \log(x_j) \quad z^T (Kx \quad y), \quad (A.5)$$

ᄶ . ᵛ .

$$\frac{L}{x_j} \quad e_j \quad n_j^{\ 1} \quad K_{:j}^T z,\ \frac{L}{z_i} \quad y_i \quad K_{i:} x, \quad (A.6)$$

ɛ̀ $K_{:j}$ K j , $K_{i:}$ K i . Э

Љ - й

$$\mathrm{grad}_x L(x,z) \quad e \quad D^{\ 1} e \quad K^T z,$$

$$\mathrm{grad}_z L(x,z) \quad y \quad Kx\ , \quad (A.7)$$

ɛ̀

$$D \quad \begin{matrix} x_1 & 0 & \cdots & 0 \\ 0 & x_2 & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & x_N \end{matrix} \quad . \quad (A.8)$$

Karush-Kuhn-Tucker .

$$K^T z \quad e \quad D^{\ 1} e,\ Kx \quad y,\ x \quad 0. \quad (A.9)$$

ᄶ $s \quad D^{\ 1} e$, . ᵛ

$$K^T z \quad s \quad e,\ Kx \quad y,\ Ds \quad e,\ x \quad 0. \quad (A.10)$$

. $(x,\ z,\ s)^T$,

$x \quad S_p \quad \{x : Kx \quad y, x \quad 0\}$, (z,s)

$S_D \quad \{(z,s) : K^T z \quad s \quad e, s \quad D^{\ 1} e \quad 0\}$. ,

$(x, z, s)^T$.

$e^T x \quad y^T z \quad x^T s \quad N$, Э ,

$$F(x,z,s) \quad \begin{matrix} Kx \quad y \\ K^T z \quad s \quad e \\ Ds \quad e \end{matrix} \quad \begin{matrix} 0 \\ 0 \\ 0 \end{matrix}\ , \quad (A.11)$$

й [0, 1] Э .

$(x_k, z_k, s_k)^T$, $F(x,z,s) \quad 0$

Newton ʔ

$$\mathrm{grad}F(x_k,z_k,s_k) \begin{matrix} d_x \\ d_z \\ d_s \end{matrix} \quad F(x_k,z_k,s_k). \quad (A.12)$$

ɣ

$$\mathrm{grad}F(x_k,z_k,s_k) \quad \begin{matrix} K & 0 & 0 \\ 0 & K^T & I \\ S_k & 0 & D_k \end{matrix}\ , \quad (A.13)$$

ɣ

$$\begin{matrix} & 0 & 0 \\ 0 & & {}^T \\ {}_k & 0 & {}_k \end{matrix} \quad \begin{matrix} {}_x \\ {}_z \\ {}_s \end{matrix} \quad \begin{matrix} {}^k \\ {}^T \quad {}_k \quad {}_k \end{matrix}\ .$$

A.1 , x_1