Monitoring of LAI and Chlorophyll Content by the Inversion of a CR Analytical Model

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Abstract Analytical canopy reflectance (CR) models have reached the level of adequacy that makes it possible to estimate vegetation parameters by the inversion of such models. The increasing efficiency of algorithms, and the increasing power of computers incite to develop procedures for the estimation of vegetation phytometrical parameters on large areas using satellite data and the inversion of theoretical CR models.

A Markov chain canopy reflectance model (MCRM) by Kuusk[1] demonstrated its ability to work on wide range of canopy optical and structural parameters even in the case of serious violations of model assumptions[1,2]. The MCRM is very computer—efficient and can be easily inverted on relatively large sets of reflectance data. Canopy reflectance models relate canopy directional reflectance to canopy structural and optical parameters. In order to solve the inverse problem on satellite images, we have to convert digital counts of satellite radiometers to ground level reflectances. For the conversion it is necessary 1) to determine satellite level radiances, i.e. to perform absolute calibration of radiometers, and 2) to estimate the ground level reflectance of targets, i.e. to perform atmospheric correction of satellite data. A straightforward procedure of pixel—by—pixel inversion of satellite images is possible, however, the inversion time increases rapidly with increasing image size and increasing number of spectral channels. The CR model inversion on large images can be performed more efficiently if some clusterization in the space of spectral signatures is applied. Here the MCR model is inverted on a 256×256 Landsat Thematic Mapper (TM) scene of a test site in Estonia. The spectral images of TM2, TM3, TM4, TM5 and TM7 taken on 8th June 1988 are used.

Key words Canopy reflectance model, Markov chain, Inversion, Chorophyll content

1 CLUSTERIZATION

Unsupervised clusterization of the scene was performed with a GIS software TopoL for Windows* using five spectral images in digital counts. The clusterization procedure divided the scene into 98 clusters, 96 of which correspond to ground and 2 to a lake.

2 CALIBRATION OF THE TM RADIOMETER

Calibration coefficients of the Landsat TM are reported in several papers[3—7]. Digital counts DC of TM are related to respective radiances b_i by a linear equation

$$b_i = \alpha_i DC_i + \beta_i$$

Coefficients α_i and β_i for 1988 are reported in Table 1.

Table 1 Calibration coefficients of Landsat-5 TM in 1988

TM	α_i, W/(m^2 μm sr DC)	β_i, W/(m^2 μm sr)
2	1.44	−3.2
3	1.09	−2.7
4	0.950	−2.3
5	0.136	−0.41
7	0.062	−0.20

* Help Service Mapping, Ltd., Praha 5, CR

3 ATMOSPHERIC CORRECTION

The atmospheric radiative transfer model 6S by Vermote *et al*.[8] is a convenient tool for the atmospheric correction of Landsat data. There were no direct measurements of atmospheric properties during the Landsat measurements. Thus the atmosphere optical parameters had to be estimated on the same scene. There is a lake (Võrtsjarv) of 270km^2 close to the study area. Aerosol optical thickness was estimated using lake radiance at the top of the atmosphere in TM3 spectral channel taking the lake reflectance equal to 0.03 at the lake surface. The estimated aerosol optical thickness $\tau_{550}=0.278$ returned visibility 17.7km which is in good accordance with observations. Downwelling diffuse red radiation was overestimated about 10% , obviously the guess of lake reflectance was too low.

Using the estimated aerosol optical thickness, and varying ground vegetation parameters, a look—up—table was created with the 6S code for every spectral channel. Later on the look—up—tables were approximated with second order polynomials, and the Landsat digital counts were converted to ground level reflectance using these polynomials.

4 INVERSION OF THE MCR MODEL

Ground level reflectance values in 5 spectral channels (TM2—TM5, TM7) were used for the estimation of canopy parameters. Inversion of the CR model was performed similar to Kuusk[9, 10]: a merit function was built which has his minimum when the best fit of model parameters is reached. Two model parameters—LAI and chlorophyll content c_{AB}—were subject to estimation. The fixed values of other model parameters are listed in Table 2.

The normalised difference vegetation index (NDVI) was calculated simultaneously. Images of NDVI, LAI, and chlorophyll content are created with a GIS program 'Idrisi for Windows*'.

Table 2 Input parameters of the Markov chain canopy reflectance model

Parameter	The fixed value	Comments
LAI	—	leaf area index
s_L	0.1	leaf size parameter
θ_m	45°	modal leaf inclination
ε	0	eccentricity of the LAD
λ_z	1.1	the Markov parameter
c_{AB}	—	chlorophyll content
c_W	0.02	water equivalent thickness, cm
N	1.3	effective number of elementary layers in a leaf
c_n	0.9	ratio of refractive indices
s_1	0.2	weight of the first Price's function of soil reflectance

*ε=0 corresponds to the spherical leaf angle distribution (LAD)

5 RESULTS AND DISCUSSION

NDVI and LAI images look similar, however there is no strong functional relation between NDVI and LAI, see Fig. 1. The estimated LAI may vary about 3 times at same values of NDVI. As result, the LAI image has more details than the NDVI image. If we compare NDVI and LAI images to the land use map we see that one can better distinguish field crops and deciduous forests on the LAI image. The estimated LAI values are in good accordance to the land use map.

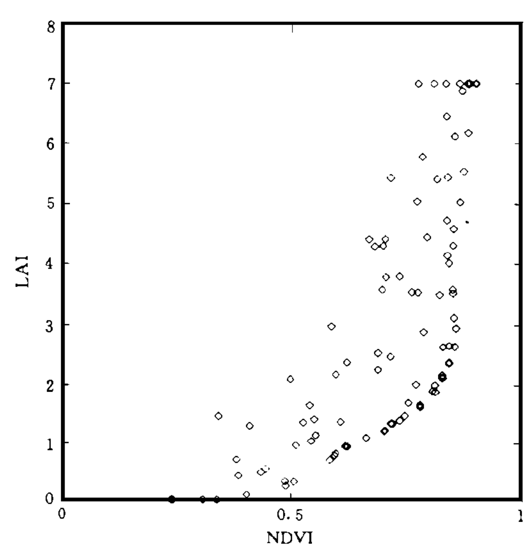

Fig. 1 LAI versus NDVI on the scene

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* Clark Labs for Cartographic Technol. and Geographic Analysis, Clark University, Worcester, MA, USA.

Field measurements of reflectance and detail phytometrical measurements were made on small plots of a barley field. Table 3 reports data of ground measurements on the test plot and satellite estimates of canopy parameters.

Field goniometer measurements (FG)[11] were performed twice - earlier in the morning and at noon. Canopy reflectance was measured with a handhold radiometer KFM of 13° FOV almost simultaneously with satellite overpass. Unfortunately the barley field was not very homogeneous. 50 pixels of the barley field belong to 9 clusters on TM image.

Table 3 Summary of field and satellite measurements on a barley canopy

	FG_1	KFM	TM_{min}	TM_{mean}	TM_{max}	FG_2
θ_{sun}	43.7°	38.2°		38.1°		35.5°
λ_{red}, nm	672	675		661		
λ_{NIR}, nm	800	800		838		
χ_{red}	0.0392	0.0426	0.0376	0.0488	0.0659	0.0369
ρ_{NIR}	0.610	0.492	0.510	0.571	0.616	0.561
S'/Q_{red}	0.71			0.699		0.76
S'/Q_{NIR}	0.74			0.725		0.82
LAI	5.02 *		5.05	6.32	7.00	
NDVI	0.879	0.841	0.771	0.842	0.885	0.877
c_{AB}			21.5	27.5	33.5	

* Destructive field measurements

The atmospherically corrected TM3 reflectance is higher in average, however, one should note some differences in central wavelengths of different radiometers. There is a good agreement of TM and field goniometer measurements in the NIR spectral channel, the KFM results are less.

The LAI estimate is higher in the average. The minimal value of LAI estimate among 50 pixels (9 clusters) is almost equal to the measured value LAI = 5.02.

There were no chlorophyll measurements. The estimated values of chlorophyll content of barley leaves are realistic.

On the whole 256×256 scene the estimated LAI values of grasslands and field crops look very realistic. The MCR model does not work well on forests, therefore the LAI of forests is obviously underestimated, especially in the case of coniferous forests. The model does not consider the clustering of foliage into crowns, and the leaf optics model can not account for the increase of absorption due branches and trunks. These inadequacies of the model are compensated by overestimated chlorophyll content of forest foliage. In the plot of LAI-chlorophyll content (Fig. 2) we see large range of chlorophyll content estimates in the case of small values of LAI. The estimated chlorophyll content converges with increasing LAI to a realistic value of 20—35 μg/cm². Pixels of low LAI and abnormally high chlorophyll content correspond to forests. The LAI of potato and vegetables was very low, on these targets the chlorophyll content estimation failed in several cases.

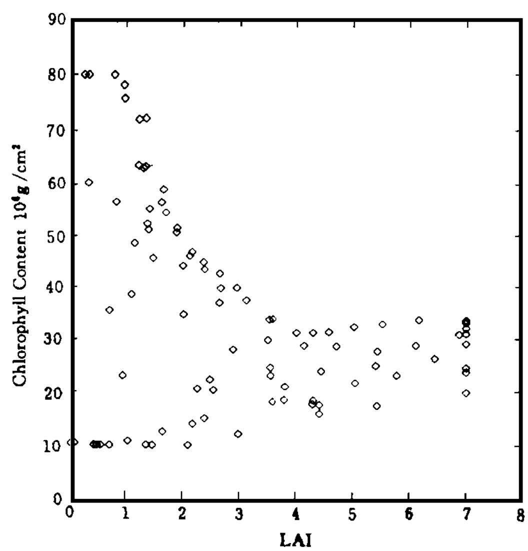

Fig. 2 Estimated LAI and chlorophyll content

6 SUMMARY

Estimation of LAI and chlorophyll content on Landsat TM image using inversion of the MCR model can be considered successful. The procedure uses the spectral information of five optical channels of TM unlike the NDVI which can use the reflectance values in two spectral channels only. The use of several spectral channels allows to estimate even more than two canopy parameters simultaneously and so better monitor canopy type and condition. The procedure can potentially use multispectral information like

AVIRIS. As the MCRM is a directional model, the off-nadir directional data of future satellite instruments (POLDER) can be used as well.

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Andres Kuusk was born on 26 Oct. 1947, and graduated from Tartu university 1970, PHD on the structure of cloud and radiation fields at the main geophys. Observatory, St. Petersburg, Dr. Geophys 1991 at Tartu university. At present senior research assoiciate at Tartu Observatory, Estonia. Member of the New York Acad. Sci., 1991. Research interest is on the field of vegetation canopy optics and optical remote sensing. Main publications: Theory of vegetation canopy hot spot (Myneni and Ross, *et al.*, Photon Vegetation Interactions, Springer, 1991.), models of vegetation canopy reflectance in Remote Sens. Environ., 1989, 1994, 1995, Agricult. Forest Meteorol., 1995.

以冠层反射解析模型的反演算法监测叶面积指数及叶绿素含量

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摘　要　以二向反射辐射信息为基础的植物（作物）冠层反射（CR）模型已经能够以其反演算法推算植物结构参数，例如叶面积指数、叶角分布、叶绿素含量等。随着计算方法效率的提高，计算机功能的发展，促进人们开发利用卫星影象图大面积估算植物结构参数的计算机程序，推动理论冠层反射模型反演算法的迅速发展。

该文在 1995 年由 Kuusk 提出的马尔可夫链冠层反射模型的基础上，发展了一个直接利用 NOAA-AVHRR 卫星和陆地卫星影象图数据进行逐个象元反演的计算程序。在 SUN-4 工作站上，反演 512 *512 个象元的叶面积指数及叶绿素含量，仅需要几个小时的时间。

另外利用地理信息系统中的集群分析法，可使反演更加有效。每个集群点只要运转一次。因此计算机需要的计算时间取决于集群点的数目而与影象图的尺寸无关。一幅影象图如有 100－200 个集群点，就有足够的植被冠层的识辨力。

该文利用爱沙尼亚塔图观象台附近的一幅陆地卫星影象图 6 个波段的数据，再现了农田的叶面积指数。由于马尔可夫链模型对于森林效果不好，对森林的叶面积的估算值均偏低。陆地卫星有 6 个波段可利用、不像 NOAA-AVHRR 只能采用两个波段。大气纠正是必须要做的，该实验采用了 Vermote（1994）的 6S 算法进行大气纠正。

由于马尔可夫链冠层反射模型是以二向反射信息为基础的，它可用于能测量倾斜（偏离星下垂直测量）的卫星数据，例如，POLDER 卫星数据等。

关键词　冠层反射模型，马尔可夫链，反演，叶绿素含量